Proceedings of the 9th international conference on disability, virtual reality and associated technologies (ICDVRAT 2012)

The 9th International Conference on

Disability, Virtual Reality and Associated Technologies

Proceedings

Edited by:

Paul Sharkey
Evelyne Klinger

10 to 12 September, 2012

Laval, France

ICDVRAT 2012

The papers appearing in this book comprise the proceedings of the 9th International Conference on Disability, Virtual Reality and Associated Technologies, held between the 10th and 12nd of September, 2012 in the Laval, France. The papers presented reflect the authors' opinions and are published as presented and without change (formatting and minor editing excepted). Their inclusion in this publication does not necessarily constitute endorsement by the editors, ICDVRAT, or the University of Reading.

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Conference Schedule at a Glance

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09:15	Welcome
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11:00 – 12:00	Keynote I: Pierre-Alain Joseph *on* Cognitive Rehabilitation
12:00 – 13:00	Session II: Cognitive Rehabilitation I
13:00	Lunch
14:30 – 15:45	Session III: Augmented Reality
15:45	Coffee
16:15 – 17:15	Session IV: Visual Impairment I
17:30 – 18:15	Session V: Hearing *&* Speech
20:00	Reception

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10:30	Coffee
11:00 – 12:00	Keynote II: Alma Merians *on* Movement Rehabilitation
12:00 – 13:00	Session VII: Training *&* Assessment I
13:00	Lunch
14:30 – 15:45	Session VIII: Design *&* Analysis
15:45	Coffee
16:15 – 16:45	Short Paper Podium Presentations
16:45 – 18:15	Poster Presentations *&* Interactive Demo Session
c. 19:30	Coach departs for Banquet Venue

Wednesday, 12 September, 2012

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10:30	Coffee
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12:15 – 13:00	Session XI: Visual Impairment II
13:00	Lunch
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16:45	Conference Closed

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Short Papers

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Introduction

The purpose of the 9th International Conference on Disability, Virtual Reality and Associated Technologies (ICDVRAT 2012) is to provide a forum for international experts, researchers and user groups to present and review how advances in the general area of Virtual Reality can be used to assist people with Disability.

ICDVRAT is now in its 16th year, with biennial conferences in the series previously held in Maidenhead, UK (1996), Skövde, Sweden (1998), Alghero, Sardinia, Italy (2000), Veszprém, Hungary (2002), Oxford, UK (2004), Esbjerg, Denmark (2006), Maia *&* Porto, Portugal (2010) and Viña del Mar/Valparaíso, Chile in 2010.

After peer review process, the International Programme Committee selected 50 Full Papers for presentation at the conference, collected into 13 plenary sessions: Stroke Rehabilitation I *&* II; Cognitive Rehabilitation I *&* II; Augmented Reality; Visual Impairment I *&* II; Hearing *&* Speech; Motor Rehabilitation; Training & Assessment I *&* II; Design *&* Analysis; and Interfacing to Virtual Environments. There will be an additional 28 Short Papers presented at a Poster Session. The conference will be held over three days between the 10th and 12nd September at the Hotel Périer du Bignon, Laval, France.

For the 2012 conference, there will be two keynote addresses, the first from Pierre-Alain Joseph addressing the issues of virtual reality for cognitive rehabilitation, and the second from Alma Merians on the topic of movement rehabilitation.

Abstracts from this conference and full papers from the previous conferences are available online from the conference web site *www.icdvrat.org*. We are also pleased to be able to provide the complete ICDVRAT archive on CD-ROM with this volume.

Acknowledgements

The Conference Chairs would like to thank the Programme Committee, for their input regarding the conference format and focus, and for their commitment to the review process, as well as the authors of all the papers submitted to the conference, the Organization Committee, Conference Sponsors, and the students who help out over the period of the conference.

On behalf of ICDVRAT 2012, we welcome all delegates to the Conference and sincerely hope that delegates find the conference to be of great interest.

Evelyne Klinger and Paul Sharkey

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International Society for Virtual Rehabilitation

Additional help in publicising the conference has been gratefully received from vrpsych-l@usc.edu, amongst many others.

ICDVRAT is a biennial conference of the International Society for Virtual Rehabilitation. The ISVR is the sponsor of the conference Best Student Full Paper and Best Student Short Paper awards.

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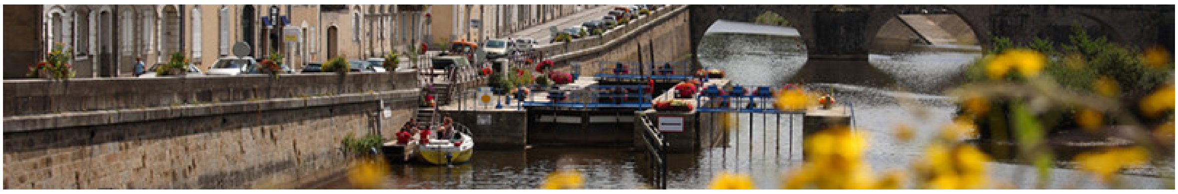
Laval ~ Town of Art and History

Evelyne Klinger

Arts et Métiers ParisTech, FRANCE

Classified as a town of art and history, thanks to its rich cultural heritage, Laval is the principal city of the Mayenne department in north-western France. Built around its castle, in the 11th century, Laval has still many of its fortifications intact, and the great chateau, with its distinctive round tower, remains an impressive sight. The River Mayenne runs beside the town and much of the life of Laval centres on this lovely river, especially in the summer. All around the town is the gentle, pastoral landscape of the region, whose rolling fields, pretty woodland and tranquil lakes all set the tone for this peaceful, friendly capital city.



Laval has stood here on the banks of the Mayenne, on the threshold of Brittany, between Normandy and Anjou, for almost a thousand years.

The old castle, around which the town of Laval grew, was built early in the 10th century by Guy II, one of the first lords of Laval. The lords, and later the counts, of Laval, among whom were the Montmorencys and the Montforts, played a prominent role in French history. After the French Revolution the counterrevolutionary Vendéen army, during the Wars of the Vendée at the end of the 18th and beginning of the 19th centuries, twice captured the castle from the Republicans. When the Republicans crushed the insurgents they executed the Prince de Talmont, lord of Laval and general of the Vendéen cavalry, in front of the castle gates.

The old quarters of the town, which have fine 16th- and 18th-century houses, two châteaux, mediaeval walls and gateways are located on the west bank slopes of the Mayenne River and are surrounded by the modern town on both sides of the river. The old castle of the counts of Laval, a medieval stronghold, has been restored and houses the Laval Museum of Naive Art, the finest collection of naive art in Europe. This is a fitting posthumous tribute to one of Laval's sons, the painter *Douanier Rousseau*. The Château Neuf (New Chateau), a Renaissance building also called the Gallery of the Counts of Laval, was restored and enlarged in the 19th century to become the Palais de Justice. The Cathedral of the Trinity with its interesting wall paintings and stone carvings, dating partly from the 11th century, has been considerably reconstructed and enlarged. Then there is the beautiful Basilica Notre Dame d'Avesnieres, notable for its magnificent steeple, and the Perrine Gardens where you will have a beautiful view of the river and the castle. Here you can visit the Alain Gerbault Centre, a tribute to the Laval-born navigator, with the replica of his boat, "the Firecrest", and then the Douanier Rousseau grave. Also well worth a visit are the imposing Porte Beucheresse, which was the gate out of town towards Brittany, and the Maison du Grand Veneur (Head Huntsman's House) at the top of the Grande Rue.

An Active Country Town

Today, Laval still plays the role of a regional market town and administrative centre, but industry has also developed, including the manufacture of machinery, electronics, plastics, and Virtual Reality. Indeed, the town of Laval has developed an academic and industrial technology centre that is at the very forefront of research into virtual reality. Every year the 'Laval Virtual' exhibition attracts specialist companies from all over the world. And on the days when Laval Virtual is open to the public, crowds of visitors come to see the latest virtual reality innovations. When you visit Laval's castle, you'll see an impressive application of this research: a virtual reconstruction of Laval in 1750.

At Laval you are never far from Nature, and the Museum of Milk will take you right to the heart of the French tradition of milk production. This is the world's largest milk and cheese museum, and the museum's ultra-modern, 5,000 square metre exhibition area will give you a full picture of all the different business activities related to milk.

Mayenne, France

Mayenne is a department in northwest France named after the Mayenne River, and is part of the region of Pays de la Loire. Bordered by the rocks and wooded hills of Alpes Mancelles in the north and the huge Parc Naturel Regional de Normandie et Maine, there is an abundance of wildlife and outdoor pursuits close by. The Mayenne River offers an abundance of activitie. From Ambrieres-les-Vallee in the north to Daon in the south, the meandering Mayenne has 85km of towpaths ideal for hikers, mountain bikers and horse riders. Unsurprisingly Mayenne is a fisherman's paradise with 4,500 kilometres of rivers. Kayaking, rambling, cycling and bird-watching are pleasant activities along the meandering river, woodlands and agricultural countryside renowned for its cheese and apples.

Virtual reality for cognitive rehabilitation: from new use of computers to better knowledge of brain black box?

P-A Joseph, J-M Mazaux, E Sorita

University of Bordeaux, FRANCE

ABSTRACT

Virtual reality based technologies are one of the emerging tools that appear to have great potential for use in cognitive rehabilitation but it still is unclear how brain capacities are involved and what is the best approach to such training. At first, virtual reality was mainly used in single user virtual environments, but social interaction should also be addressed using collaborative virtual environments (CVE). In a CVE, multiple users can interact and collaborate with each other, solve complex tasks and learn with each other. Regarding to impact of behavioral disturbances in family stress and social re-entry, such tools need to have a wider use in future years.

Quantitative aspects are encouraging as some improvement have been shown after few training sessions. Home retraining or telerehabilitation based on VR may bridge the gap between lack of specialized resources and growing number of patients. Qualitative design of VR tools is more questionable. Choice of errorless or errorfull designs may depend on the severity of disturbances. Most VR tools emphasize the explicit component of tasks, even procedural aspects are a main strength of VR retraining programs. VR and augmented reality tools give various stimuli and indicators but their best modalities stay unclear, as most data are coming from learning studies in normal subjects more than rehabilitation studies in brain injured patients. Specific research studies to explore impact of sensorial transmodal effects and emotional involvement in VR tasks are requested. Rehabilitation protocols utilizing virtual environments are moving from single applications to cognitive impairment (i.e. alert, memory, neglect, language, executive functions) to comprehensive rehabilitation programs with the aim of efficient improvement in autonomy and transfer of benefits in real life conditions. A core issue that presents challenges to rehabilitation is decreased ability of persons with brain injury to transfer learning from one situation or context to another. The multicontext approach to cognitive rehabilitation proposes treatment methods for teaching use of strategies across a wide range of meaningful activities to promote generalization and enhance functional performance.

VR offers a very promising and exciting support for cognitive rehabilitation but we have to move from mimicking “in room” or desk rehabilitation practice to specific VR programs to maximize benefits and to get optimal improvement in cognitive and behavioral autonomy of patients.

P-A Joseph, J-M Mazaux, E Sorita, Virtual reality for cognitive rehabilitation: from new use of computers to better knowledge of brain black box?, *Keynote Address, Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 1–8, Laval, France, 10 – 12 Sept. 2012.

Keynote: Alma Merians

Movement rehabilitation in virtual reality from then to now: how are we doing?

A S Merians, G Fluet, E Tunik, Q Qiu, S Saleh, S Adamovich

University of Medicine and Dentistry of New Jersey, USA

New Jersey Institute of Technology, USA

ABSTRACT

During the past decade there has been a continuous exploration of how virtual environments can be used to facilitate motor recovery and relearning after neurological impairment. The goals for using virtual environments have been to either improve patients' rehabilitation outcomes beyond our current capabilities, or to supplement labor intensive and time consuming therapies with technology based interventions. After over a decade of investigation it seems appropriate to determine whether we are succeeding in meeting our goals.

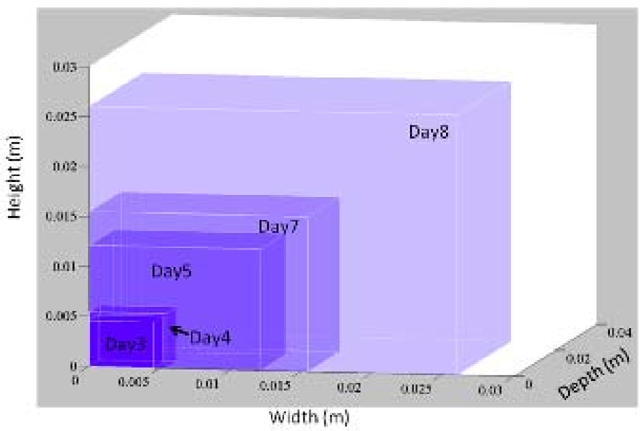


Figure 1. *Workspace expands gradually and continuously throughout the training period.*

A S Merians, G Fluet, E Tunik, Q Qiu, S Saleh, S Adamovich, Movement rehabilitation in virtual reality from then to now: how are we doing?, *Keynote Address, Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 9–15, Laval, France, 10 – 12 Sept. 2012.

Session I: Stroke Rehabilitation I

Robotic/virtual reality intervention program individualized to meet the specific sensorimotor impairments of an individual patient: a case study

G G Fluet, A S Merians, Q Qiu, S Saleh, V Ruano, A R Delmonico, S V Adamovich

University of Medicine & Dentistry of New Jersey, USA

New Jersey Institute of Technology, USA

ABSTRACT

A majority of studies examining repetitive task practice facilitated by robots for the treatment of upper extremity paresis utilize standardized protocols applied to large groups. Others utilize interventions tailored to subjects but don't describe the clinical decision making process utilized to develop and modify interventions. This study will describe a virtually simulated, robot-based intervention customized to match the goals and clinical presentation of a gentleman with upper extremity hemiparesis secondary to stroke. MP, the subject of this case, is an 85 year-old man with left hemiparesis secondary to an intracerebral hemorrhage five years prior to examination. Outcomes were measured before and after a one month period of home therapy and after a one month virtually simulated, robotic intervention. The intervention was designed to address specific impairments identified during his PT examination. When necessary, activities were modified based on MP's response to his first week of treatment. MP's home training program produced a 3 second decline in Wolf Motor Function Test (WMFT) time and a 5 second improvement in Jebsen Test of Hand Function (JTHF) time. He demonstrated an additional 35 second improvement in JTHF and an additional 44 second improvement in WMFT subsequent to the robotic training intervention. 24 hour activity measurement and the Hand and Activities of Daily Living scales of the Stroke Impact Scale improved following the robotic intervention Based on his responses to training we feel that we have established that, a customized program of virtually simulated, robotically facilitated rehabilitation was feasible and resulted in larger improvements than an intensive home training program in several measurements of upper extremity function in our patient with chronic hemiparesis.

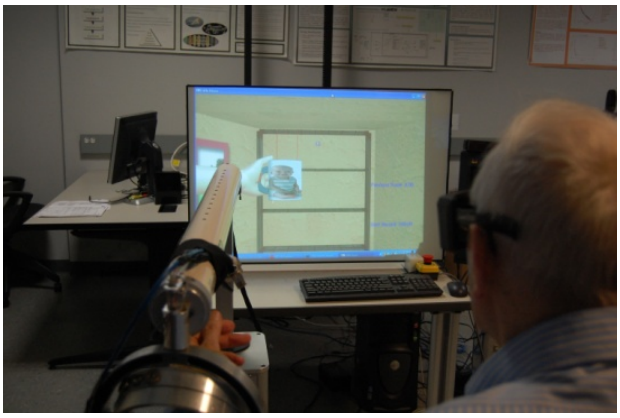


Figure 5. *Subject performing Cup Reaching simulation.*

G G Fluet, A S Merians, Q Qiu, S Saleh, V Ruano, A R Delmonico, S V Adamovich, Robotic/virtual reality intervention program individualized to meet the specific sensorimotor impairments of an individual patient: a case study, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 17–24, Laval, France, 10 – 12 Sept. 2012.

Can a home based virtual reality system improve the opportunity for rehabilitation of the upper limb following stroke?

P J Standen, K Threapleton, L Connell, A Richardson, D J Brown, S Battersby, F Platts

University of Nottingham, Nottingham, UK
University of Central Lancashire, UK
Erewash Community Occupational Therapy Service, Derbyshire, UK
Nottingham Trent University, UK
Sherwood Forest Hospitals NHS Foundation Trust, Nottinghamshire, UK

ABSTRACT

Many stroke survivors fail to regain functional use of their impaired upper limb yet access to the rehabilitation required is limited. One route through which this may be achieved is through the adoption of virtual reality and interactive video gaming. We have been developing a home based system that employs infra red capture to translate the position of the hand, fingers and thumb into game play but do the patients actually use it to the recommended level and if not, why not? Performance data collected by the software from three participants allocated to the intervention group in a feasibility RCT indicate that the pattern of play is variable and can fall far short of the recommendations participants were given. Interviews with participants at the end of the intervention and observations by the research team indicate the barriers to recommended use but also some of the characteristics of the intervention that demonstrate its potential for improving the opportunity for rehabilitation of the upper limb following stroke.

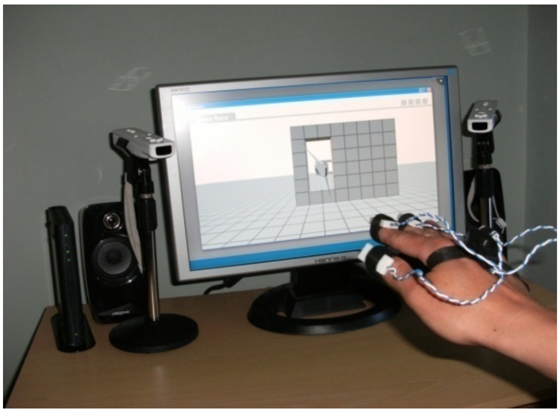


Figure 1. *The virtual glove.*

P J Standen, K Threapleton, L Connell, A Richardson, D J Brown, S Battersby, F Platts, Can a home based virtual reality system improve the opportunity for rehabilitation of the upper limb following stroke?, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 25–32, Laval, France, 10 – 12 Sept. 2012.

Session I: Stroke Rehabilitation I

Development and validation of tele-health system for stroke rehabilitation

P L Weiss, R Kizony, O Elion, S Harel, I Baum-Cohen,
T Krasovsky, Y Feldman, M Shani

Gertner Institute for Epidemiology and Health Policy Research, Tel Hashomer, ISRAEL
University of Haifa, ISRAEL
Sheba Medical Center, Tel Hashomer, ISRAEL
McGill University, Montreal, CANADA

ABSTRACT

Tele-rehabilitation refers to the use of information and communication technologies to provide rehabilitation services to people in their homes or other environments. The objective of this paper is to present the development, validation and usability testing of a low-cost, markerless full body tracking virtual reality system designed to provide remote rehabilitation of the upper extremity in patients who have had a stroke. The Methods and Results sections present the progress of our work on system development, system validations and a feasibility/usability study. We conclude with a brief summary of the initial stages of an intervention study and a discussion of our findings in the context of the next steps. The validation study demonstrated considerable accuracy for some outcomes (i.e., shoulder "pitch" angle, elbow flexion, trunk forward and side-to-side deviation). In addition positive responses were received from the clients who participated in the feasibility study. We are currently at the process of improving the accuracy of the system as well as conducting a randomized clinical trial to assess the effectiveness of the system to improve upper extremity function post-stroke.

Figure 2. *Screenshot showing the Hamburger short order cook task. The client's order is specified in the conversation balloon and the ingredients are listed to the right of the screen. The top shelf is adjustable to make selections harder or easier.*

P L Weiss, R Kizony, O Elion, S Harel, I Baum-Cohen, T Krasovsky, Y Feldman, M Shani, Development and validation of tele-health system for stroke rehabilitation, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 33–40, Laval, France, 10 – 12 Sept. 2012.

Using a virtual supermarket as a tool for training executive functions in people with mild cognitive impairment

R Kizony, M Korman, G Sinoff, E Klinger, N Josman

University of Haifa, ISRAEL

Sheba Medical Center, Tel Hashomer, ISRAEL

School for Special Education, Tzohar Le'Tohar, Rechasim, ISRAEL

Carmel Medical Center, Haifa, ISRAEL

Arts et Métiers ParisTech Angers-Laval, FRANCE

ABSTRACT

Cognitive and executive functions (EF) intervention programs for people with mild cognitive impairment (MCI) has not been studied enough, especially with the use of virtual reality. The purpose of the current study was to examine the effectiveness of using the Virtual Action Planning – Supermarket (VAP-S) to improve performance of a shopping task and EF among people with MCI. Seven participants with non-amnestic or multi-domain amnestic MCI completed the study protocol which followed an ABA single subject design. The outcome measures included the Multiple Errands Test (MET) to assess EF while performing a shopping task and the WebNeuro to assess EF impairments. Results showed that 4 participants improved their EF as assessed by the WebNeuro and 4 improved their performance of the shopping task in the MET. It seems that in some cases a learning effect occurred which explains why some of the participants did not improve. The results point to the potential of using the VAP-S as an intervention tool for training EF in people with MCI.

R Kizony, M Korman, G Sinoff, E Klinger, N Josman, Using a virtual supermarket as a tool for training executive functions in people with mild cognitive impairment, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 41–46, Laval, France, 10 – 12 Sept. 2012.

Session II: Cognitive Rehabilitation I

Rehabilitation tools along the reality continuum: from mock-up to virtual interactive shopping to a living lab

S Y Hadad, J Fung, P L Weiss, C Perez, B Mazer, M F Levin, R Kizony

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Sheba Medical Center, Tel Hashomer, ISRAEL

McGill University, Montreal, CANADA

Jewish Rehabilitation Hospital, Laval, Quebec, CANADA

ABSTRACT

The purpose of this study was to compare shopping performance using the 4-item test, between three types of environments; a real environment (small, in-hospital “cafeteria”), a store mock-up (physical simulation) and a virtual environment (Virtual Interactive Shopper-VIS), in a post-stroke group compared to a control group. To date, 5 people with stroke and 6 controls participated in the study. Participants performed the original 4-item test (“buy” 4 items) in the VIS and the store mock-up as well as a modified 4-item test (“buy” 4 items with budget constraints) in all three environments. Results were analyzed descriptively and findings to date, indicate that the post-stroke group performed more slowly than the control group. In addition, in both groups, the time to complete the test within the VIS was longer than in the store mock-up and the cafeteria. Performance in the VIS, the store mock-up and the cafeteria were correlated in the post-stroke group. Finally, participants’ responses to their experience in the VIS were positive. The preliminary results of this small sample show that the test within the VIS is complex and realistic and may be used to assess and train the higher cognitive abilities required for shopping.

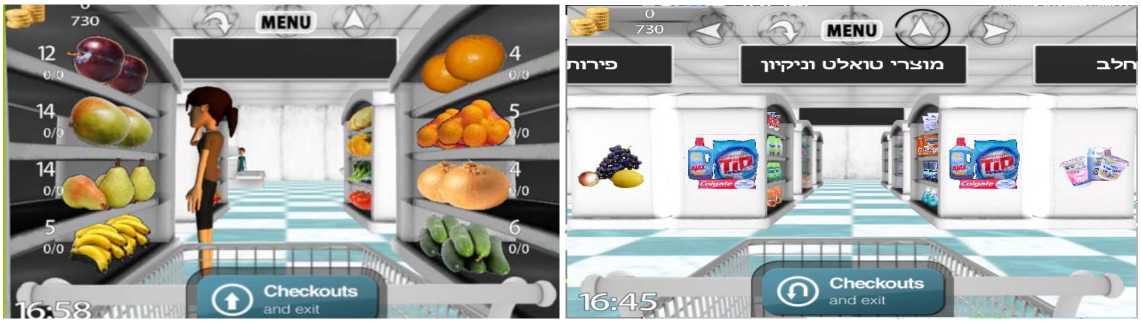

Figure 1. *Two screenshots of the Virtual Interactive Shopper (VIS).*

S Y Hadad, J Fung, P L Weiss, C Perez, B Mazer, M F Levin, R Kizony, Rehabilitation tools along the reality continuum: from mock-up to virtual interactive shopping to a living lab, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 47–52, Laval, France, 10 – 12 Sept. 2012.

So much technology, so little time: factors affecting use of computer-based brain training games for cognitive rehabilitation following stroke

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University of Nottingham, UK

ABSTRACT

Rehabilitation following stroke typically focuses on regaining use of the affected lower and upper limbs. Impairment of cognitive processes, however, is predictive of rehabilitation outcomes. Stroke survivors and their caregivers report difficulty finding time to practice gait and upper limb training at home due to the time demands of routine activities of daily living (ADL), leaving little time for cognitive retraining. Cognitive activities have become more readily accessible to the home user through web-based games that engage brain functions often disrupted by stroke. With neuropsychological testing, it is possible to "prescribe" brain training that targets the specific cognitive functions disrupted by an individual's acquired brain injury. We asked if computer-based braining training were made available in-home at no cost, would stroke survivors complete the training? Five stroke survivors participated, none completed the recommended 40 training sessions. Interviews with participants and caregivers reveal barriers to training including physical and cognitive limitations, as well as time and fatigue management. Training also showed effects on ADLs and mood.

Figure 1. *Familiar Faces. This game involves the user working as a server in a seaside restaurant. Each visitor has a name and places an order. The server must remember the orders and customer's names to earn a large tip. The game exercises associative memory for verbal and visual information. As performance on the task improves, more characters and more complicated orders are presented. The user must remember names within session and from previous sessions. This screen shot appears courtesy of* [Hardy & Scanlon, 2009].

B B Connor, P J Standen, So much technology, so little time: factors affecting use of computer-based brain training games for cognitive rehabilitation following stroke, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 53–59, Laval, France, 10 – 12 Sept. 2012.

3D augmented reality applied to the treatment of neuropathic pain

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Université Libre de Bruxelles, Brussels, BELGIUM
Erasme Hospital, Brussels, BELGIUM

ABSTRACT

Neuropathic pain is characterized by a permanent or recurrent background pain including stinging, tingling, allodynia, burning, shock or stabbing sensations. It significantly alters the patient quality of life. Such painful conditions are observed in the case of phantom limb pain (PLP) and complex regional pain syndrome (CRPS), and are difficult to treat effectively. Recent studies show the crucial role of the central nervous system in these pathologies and suggest a link to the plasticity of the latter. Mirror visual feedback (MVF) is often used in case of amputation, CRPS or stroke to restore normal cortical organization and to lower pain intensity. We have conceived an augmented reality (AR) system that applies the principle of MVF without requiring the use of a physical mirror. The system strengthens the patient's immersion and concentration by using realistic, natural looking 3D images that are acquired, processed and displayed in 3D, in real time. Our system is based on standard inexpensive hardware and is easy to install and to use. This makes it perfectly suitable for use in a therapist's practice or at home. The preliminary results of clinical tests show that the system can significantly reduce the pain, after only a few training sessions.

Figure 1. *Application of a virtual mirror to a 3D image. The left part shows the original image. In the middle part we see the virtual mirror in pink and the safe zone in green. The right part shows how the 3D mesh that is on the right side of the mirror is duplicated symmetrically to the left side, except inside the safe zone.*

B Penelle, D Mouraux, E Brassinne, T Tuna, A Nonclercq, N Warzée, 3D augmented reality applied to the treatment of neuropathic pain, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 61–68, Laval, France, 10 – 12 Sept. 2012.

Augmented reality improves myoelectric prosthesis training

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ABSTRACT

This paper presents the ARM Trainer, a new augmented reality-based system that can be used to train amputees in the use of myoelectric prostheses. The ARM Trainer provides users with a natural and intuitive method to develop the muscles used to control a myoelectric prosthetic. In addition to improving the training process, the new interface has the potential to mitigate psychological issues arising from amputation that are not addressed by existing approaches (e.g., self-image, phantom limb pain). We conducted an empirical study comparing our system to an existing commercial solution (Myoboy) and found the ARM Trainer to be superior along a number of subjective dimensions (enjoyment, perceived effort, competency, and pressure). We also found no significant difference in terms of muscle control development between the two systems. This study shows the potential of augmented reality-based training systems for myoelectric prostheses.

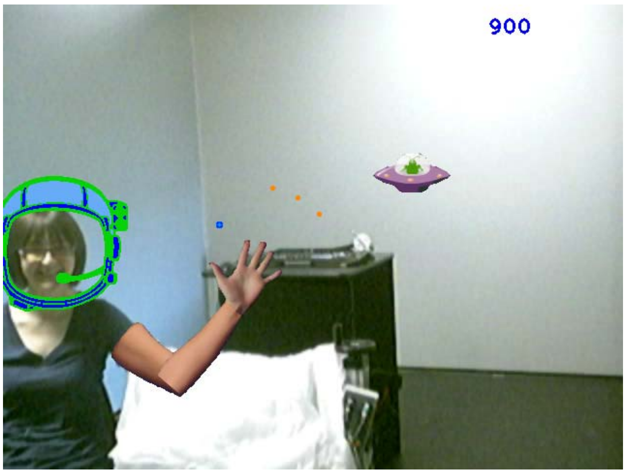

Figure 1. *The ARM Trainer system, as displayed to the user.*

F Anderson, W F Bischof, Augmented reality improves myoelectric prosthesis training, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 69–76, Laval, France, 10 – 12 Sept. 2012.

Development of an augmented treadmill for the rehabilitation of children with cerebral palsy: pilot perspectives from young healthy adult users

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University of Surrey, Guildford, Surrey, UK
Queen Mary's Hospital, London, UK

ABSTRACT

A Real-time Treadmill Speed Control Algorithm (RTSCA) has been developed for gait rehabilitation of children with cerebral palsy (CP). The objective of the work described in this paper was to investigate the feasibility of the RTSCA prior to use by children with CP. Thirteen healthy subjects aged between 19 and 25 were recruited to walk on the treadmill using conventional speed buttons without the virtual reality (VR) environment, and the RTSCA with and without VR. The participants were asked to undertake three treadmill tests and to complete a questionnaire to provide feedback on the control of the treadmill. The descriptive results show that for 10 participants changing walking speed from stationary when using the RTSCA was similar or more comfortable to using conventional treadmill speed control buttons. For those who found it less comfortable the core issue was insufficient time to practise with the system. All the participants were satisfied with the safety and the performance of the RTSCA when incorporated into the VR scenario. A Wilcoxon test was conducted to examine whether there was a significant difference between walking speeds on the treadmill when using the conventional speed buttons and the RTSCA. The results showed that participants walked at significantly higher speeds when using the RTSCA. This may suggest that they walked more naturally or confidently on the treadmill when using the RTSCA as compared to the use of conventional treadmill speed control buttons.

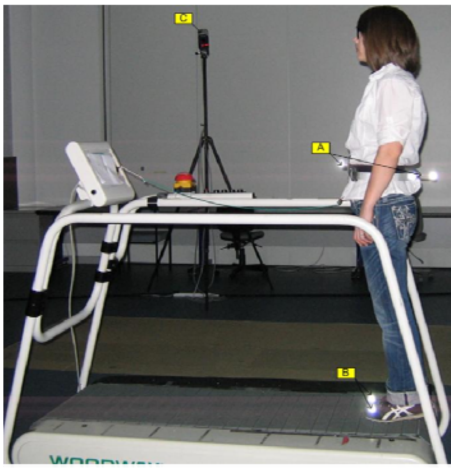

Figure 2. *A participant using the RTSCA. A: pelvis cluster – a sprung loaded frame with 3-point contact to calculate the origin of the pelvis segment; B: markers on feet; C: one of the eight motion capture cameras used.*

M Al-Amri, D Abásolo, S Ghoussayni, D Ewins, Development of an augmented treadmill for the rehabilitation of children with cerebral palsy: pilot perspectives from young healthy adult users, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 77–85, Laval, France, 10 – 12 Sept. 2012.

Session III: Augmented Reality

Mathematical literacy for everyone using arithmetic games

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ABSTRACT

An innovative mathematics game shown to be effective for low-achieving mainstream students is tested in special education for learners with intellectual disabilities. The game relies on a graphical, intuitive representation for numbers and arithmetic operations to foster conceptual understanding and numbers sense, and provides a set of 2-player games to develop strategic thinking and reasoning skills. The game runs on computers and interactive white boards, and as an augmented reality application at a science centre. We compare its use in special education and mainstream education with respect to usage, performance levels and learning gain. The game has been used by teachers in special educations, with gains in mathematical understanding, strategic thinking and communication skills as effects.

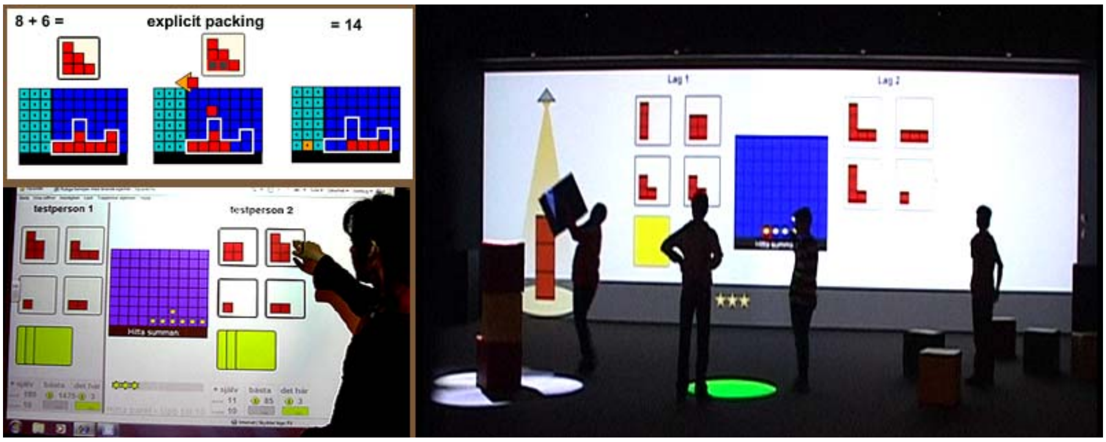

Figure 3. *Explicit carrying operation as packing blocks into boxes (top left), game on interactive white board (bottom left) and game as augmented reality application in science center (right).*

L Pareto, Mathematical literacy for everyone using arithmetic games, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 87–96, Laval, France, 10 – 12 Sept. 2012.

Fitness improved for individuals post-stroke after virtual reality augmented cycling training

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Northeastern University, Boston, MA, USA

VRehab LLC, USA

ABSTRACT

A virtual reality (VR) augmented cycling system was developed to address motor control and fitness deficits. In this paper we report on the use of the system to train fitness for individuals (N=4) in the chronic phase post-stroke who were limited community ambulators. Fitness was evaluated using a sub-maximal bicycle ergometer test before and after training. There was a statistically significant 13% ($p = .035$) improvement in VO_2 (with a range of 6-24.5 %). For these individuals, VR augmented cycling, using their heartrate to set the avatar's speed, fostered training of sufficient duration and intensity to promote fitness.

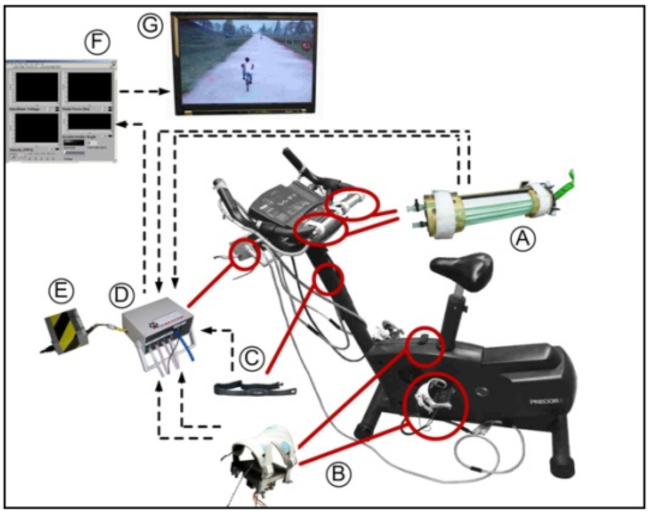

Figure 1. *Virtual Reality Augmented Cycling Kit (VRACK): A: Sensorized handle bars, B: Sensorized pedals, C: Heart Rate sensor and monitor D: Controller E: Power source F: Practitioner interface (where the target heart rate is set) G: Virtual Environment.*

J E Deutsch, M J Myslinski, R Ranky, M Sivak, C Mavroidis, J A Lewis, Metabolic response to virtual reality augmented cycling training, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 97–102, Laval, France, 10 – 12 Sept. 2012.

Haptic presentation of 3D objects in virtual reality for the visually disabled

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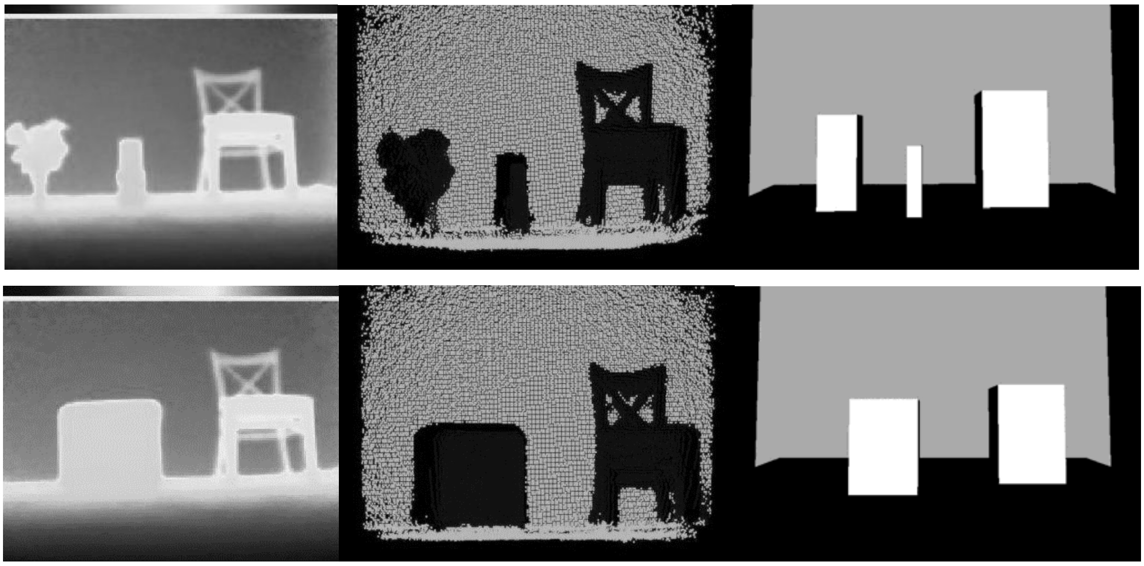
ABSTRACT

The paper presents an initial research on haptic perception of 3D objects in a virtual reality environment for aiding the visually disabled persons in learning new routes and obstacle identification. The study spans a number of fields, from the very technical, such as scene segmentation and obstacle detection algorithms to psychological aspects such as the effectiveness in utilizing haptic information. The authors constructed a prototype system for the tactile presentation of real objects in a virtual reality.



a) b) c)

Figure 3. *The virtual scene modeling process: a 2.5D depth map of the scene a), the segmented scene b) (grey – found planes, black – found obstacles), the reconstructed scene for the tactile presentation c) (the obstacles are replaced by cubes, see the text).*

M Moranski, A Materka, Haptic presentation of 3D objects in virtual reality for the visually disabled, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 103–109, Laval, France, 10 – 12 Sept. 2012.

Session IV: Visual Impairment I

When sighted people are in the skin of visually impaired ones: perception and actions in virtual reality situation

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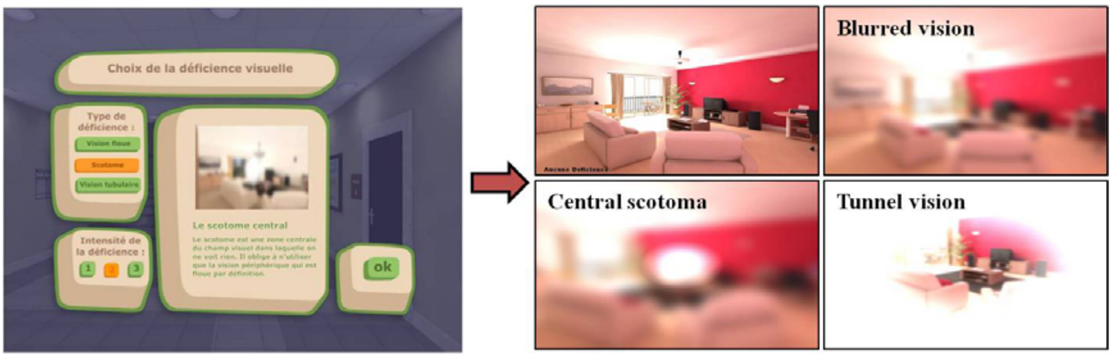
Institut pour malvoyants des Hauts Thébaudières, Vertou, FRANCE

ABSTRACT

Most of us do not know how a visually impaired person perceives and acts within the environment in everyday life. In this context, an experimental study was conducted using a virtual reality simulation in which sighted people were immersed in low vision situations: Blurred vision, Tunnel vision, central Scotoma. After a brief familiarization procedure with a virtual reality tool called “SENSIVISE” which includes a virtual apartment, 24 adults had to explore two rooms through low vision simulation or full vision (as control group) to identify their location, and then were instructed to find particular targets. Perception and actions performances were measured in terms of time needed to answer questions related to visual perception, and distances between the participants’ body and the screen. The results show that low vision simulation impairs perception among sighted people. It was expressed by a statistically significant effect of lower times needed to execute tasks compared to the control condition. Consequently, the sighted individuals realized how it is difficult to perceive and move when vision is limited.



a) b)

Figure 1: *A snapshot of the environment. a) allows to choose form and intensity of low vision displayed (on the left); and concurrently inform about the selected form (on the right); b) results of the three simulations; Control condition and Blurred vision on the left and right top respectively; central Scotoma and Tunnel vision down left and right respectively.*

Y Boumenir, A Kadri, N Suire, C Mury, E Klinger, When sighted people are in the skin of visually impaired ones: perception and actions in virtual reality situation, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 111–119, Laval, France, 10 – 12 Sept. 2012.

Dynamic spatial positioning system based on sounds and augmented reality for visually impaired people

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National Institute for Space Research, São Paolo, BRAZIL

ABSTRACT

This paper presents an application which intends to exercise spatial association of a three dimensional stimulus with its corresponding motor feedback, inspired on the Ping Pong Game. The application uses a low cost and easily built artifact, enhanced with an augmented reality layer provided by a free authoring tool. The augmented reality resources empower the artifact with sound feedback, so visually impaired people can use it. Besides, the visual feedback can be useful for non-visually impaired people and also for therapists, who can prepare exercises, promoting a therapeutic application and involving social inclusion capabilities.

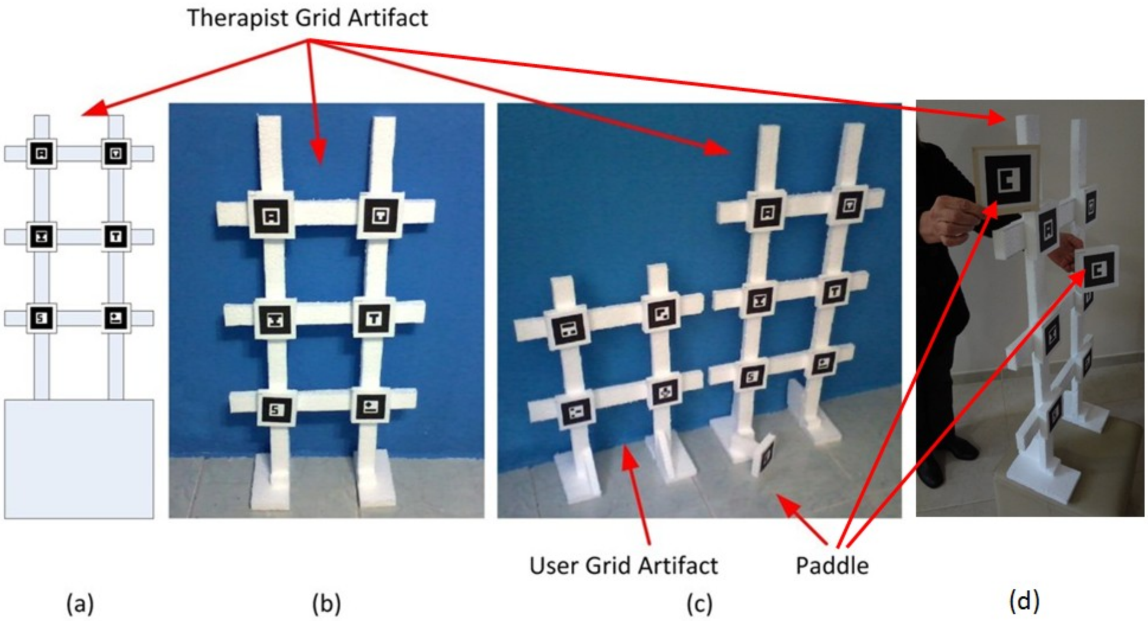

Figure 4. *Artifact Views: (a) Conception; (b) Therapist; (c) User and Therapist; (d) Prototype in action.*

C Kirner, C S Cerqueira, T G Kirner, Dynamic spatial positioning system based on sounds and augmented reality for visually impaired people, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 121–129, Laval, France, 10 – 12 Sept. 2012.

Videogaming for wayfinding skills in children who are blind

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Pontifical Catholic University of Valparaíso, Viña del Mar, CHILE

ABSTRACT

There are several problems faced by people who are blind when navigating through unfamiliar spaces, and especially open spaces. One way to mitigate these problems is by getting to know the spaces prior to actual navigation, through the use of virtual environments represented through audio and haptic interfaces. In exploring the possibilities for further improving navigation through such spaces; it was especially interesting to study the option of simulating the real body movement of a learner who is n during his interaction with a virtual environment. To achieve this the design, implementation and impact evaluation of an audio and haptic-based videogame called MovaWii is proposed, in which a real physical space is represented virtually, where learners who are blind interact through their own body movements and use of the Wiimote controllers of the Nintendo Wii console in order to navigate through unknown virtual spaces. The results demonstrated a videogame that allows for the development of orientation and mobility skills in learners who are blind, as it serves as a supporting tool for the construction of a mental map of the virtual space navigated through the integration of its audio and haptic components. In addition, learners could transfer the information obtained from virtual to the real world physical space, through which they were then able to navigate autonomously and efficiently.

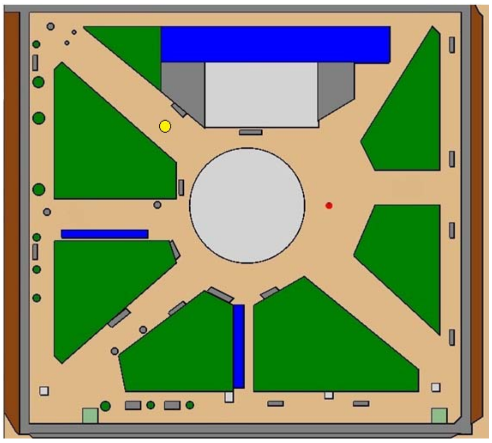

Figure 2. *Graphic interface of the videogame.*

J Sánchez, M Espinoza, J M Garrido, Videogaming for wayfinding skills in children who are blind, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 131–140, Laval, France, 10 – 12 Sept. 2012.

Appreciating speech through gaming

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University of the Philippines Diliman, Quezon City, PHILIPPINES

ABSTRACT

This paper discusses the Speech and Phoneme Recognition as an Educational Aid for the Deaf and Hearing Impaired (SPREAD) application and the ongoing research on its deployment as a tool for motivating deaf and hearing impaired students to learn and appreciate speech. This application uses the Sphinx-4 voice recognition system to analyze the vocalization of the student and provide prompt feedback on their pronunciation. The packaging of the application as an interactive game aims to provide additional motivation for the deaf and hearing impaired student through visual motivation for them to learn and appreciate speech.

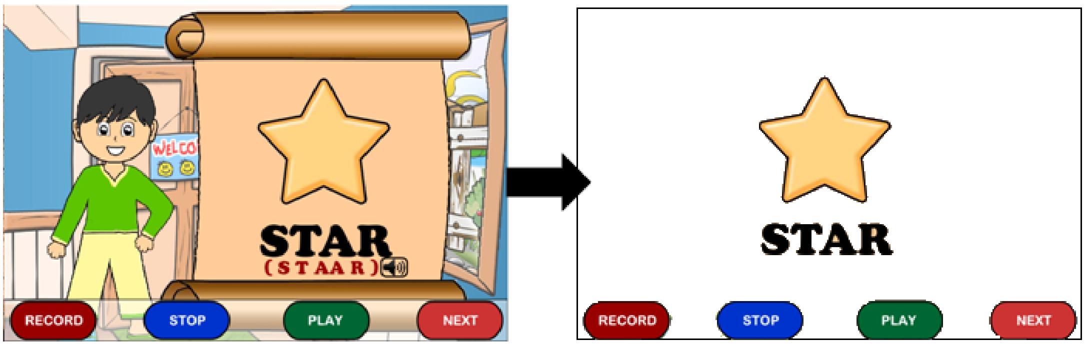

Figure 4. *Proposed simpler interface.*

S T Sadural, M T Carreon, Appreciating speech through gaming, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 141–148, Laval, France, 10 – 12 Sept. 2012.

Helping deaf and hard-of-hearing people by combining augmented reality and speech technologies

M R Mirzaei, S Ghorshi, M Mortazavi

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ABSTRACT

Recently, many studies have shown that the Augmented Reality (AR), Automatic Speech Recognition (ASR) and Text-to-Speech Synthesis (TTS) can be used to help people with disabilities. In this paper, we combine these technologies to make a new system, called "ASRAR", for helping deaf people. This system can take a narrator's speech and convert it into a readable text, and show the text directly on AR displays. Since most deaf people are unable to make meaningful sounds, we use a TTS system to make the system more usable for them. The results of testing the system show that its accuracy is over 85 percent, using different ASR engines, in different places. The results of testing TTS engines show that the processing time is less than three seconds and the spelling of correct words is 90 percent. Moreover, the result of a survey shows that more than 80 percent of deaf people are very interested in using the ASRAR system for communication.

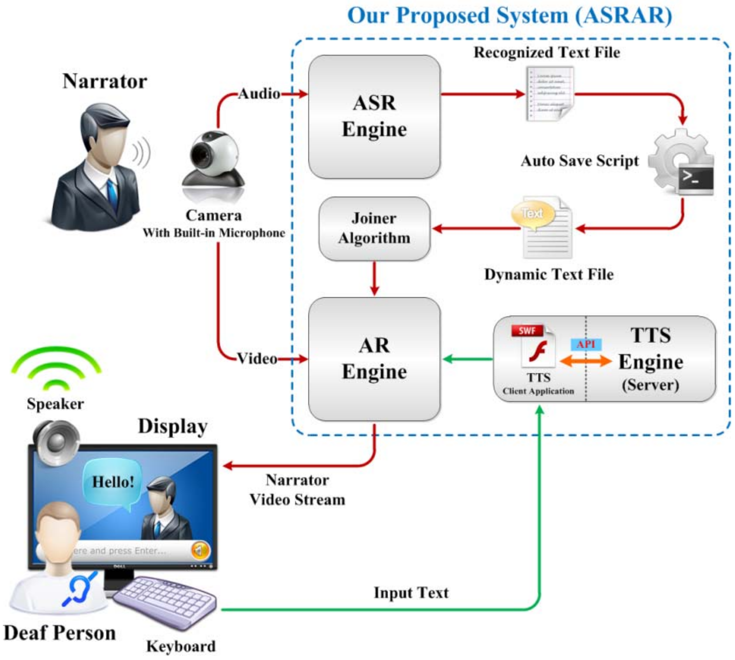

Figure 2. *The ASRAR system structure.*

M R Mirzaei, S Ghorshi, M Mortazavi, Helping deaf and hard-of-hearing people by combining augmented reality and speech technologies, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 149–158, Laval, France, 10 – 12 Sept. 2012.

Evaluation of the prototype mobile phone app *Pugh*: a 3D cartoon character designed to help deaf children to speech read

D M Shaw, M Patera, E Paparidou, R Wolff

University of Salford, Greater Manchester, UK

German Aerospace Center, Simulation and Software Technology, Brunswick, GERMANY

ABSTRACT

Pugh, a 3D cartoon character, is a prototype smartphone application developed at the University of Salford. Its purpose is to provide speech-reading exercises for hard of hearing and deaf children. This paper discusses the design of the application, the test process and acknowledges that the technological limitations of the platform and the character's non-human characteristics provide some interesting challenges. A preliminary test was conducted to evaluate speech perception and lipreading from *Pugh*. The findings proved that *Pugh* is not an accurate speaker. Further development of the lip movement and facial expressions is required in order to achieve accuracy.

Figure 1. *A screenshot of Pugh as he appears in the iPhone application*

D M Shaw, M Patera, E Paparidou, R Wolff, Evaluation of the prototype mobile phone app Pugh: a 3D cartoon character designed to help deaf children to speech read, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 159–165, Laval, France, 10 – 12 Sept. 2012.

Web-based home rehabilitation gaming system for balance training

V I Kozyavkin, O O Kachmar, V E Markelov, V V Melnychuk, B O Kachmar

International Clinic of Rehabilitation, Truskavets, UKRAINE

ABSTRACT

Currently, most systems for virtual rehabilitation and motor training require quite complex and expensive hardware and can be used only in clinical settings. Now, a low-cost rehabilitation game training system has been developed for patients with movement disorders; it is suitable for home use under the distant supervision of a therapist. It consists of a patient-side application installed on a home computer and the virtual rehabilitation Game Server in the Internet. System can work with different input gaming devices connected through USB or Bluetooth, such as a Nintendo Wii balance board, a Nintendo Wii remote, a MS Kinect sensor, and custom-made rehabilitation gaming devices based on a joystick. The same games can be used with all training devices. Assessment of the Home Rehabilitation Gaming System for balance training was performed on six patients with Cerebral Palsy, who went through daily training sessions for two weeks. Preliminary results showed balance improvement in patients with Cerebral Palsy after they had completed home training courses. Further studies are needed to establish medical requirements and evidence.

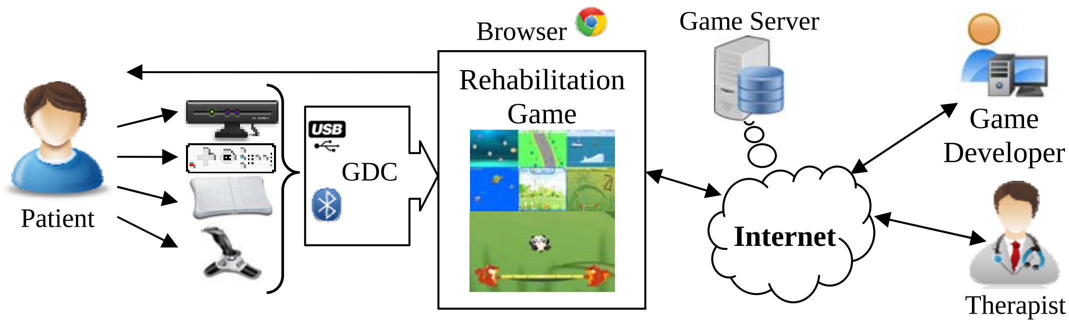

Figure 1. *Scheme of the Web-based virtual rehabilitation system.*

V I Kozyavkin, O O Kachmar, V E Markelov, V V Melnychuk, B O Kachmar, Web-based home rehabilitation gaming system for balance training, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 167–173, Laval, France, 10 – 12 Sept. 2012.

Balance rehabilitation using custom-made Wii Balance Board exercises: clinical effectiveness and maintenance of gains in acquired brain injury population

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Universitat Politècnica de València, SPAIN
Univesity of Jaume I, Castellón, SPAIN
Fundación Hospitales NISA, Valencia, SPAIN

ABSTRACT

Balance disorders are a common impairment of some of the pathologies with the highest incidence and prevalence rates. Conventional physical therapy treatment focuses on the rehabilitation of balance skills in order to enhance patients' self-dependency. In the last years, some studies have reported the clinical benefits of virtual reality systems in the balance recovery. The force platform Wii Balance Board has been adopted with rehabilitative purposes by many services due to its low cost and widespread battery of exercises. However, this entertainment system is oriented to healthy people and cannot adapt to the patient's motor (and possible cognitive) deficits. In previous studies we have developed custom-made adaptive exercises that use the Wii Balance Board with promising results in acquired brain injury population. In this contribution, we present some conclusions derived from the past and undergoing clinical studies.

Figure 2. *Patients interacting with the second prototype of the system*

R Lloréns, S Albiol, J A Gil-Gómez, M Alcañiz, C Colomer, E Noé, Balance rehabilitation using custom-made Wii Balance Board exercises: clinical effectiveness and maintenance of gains in acquired brain injury population, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 175–180, Laval, France, 10 – 12 Sept. 2012.

Upper-body interactive rehabilitation system for children with cerebral palsy: the effect of control/display ratios

T Yamaguchi, P Richard, F Veaux, M Dinomais, S Nguyen

Université d'Angers, Angers, FRANCE

Centre les Capucins, Angers, FRANCE

ABSTRACT

We have developed a virtual reality rehabilitation system using upper-body interaction with Microsoft KinectTM. With the use of KinectTM , the system enables a patient a full-range of avatar movements to adapt the Control/Display (C/D) ratio of a limb's position in 3D space. In this paper, we have explored the effectiveness of C/D ratios in our prototype application to analyze user performance, work load, and user enjoyment with university students without motor impairments. Our findings suggest that the C/D ratio is related to task difficulty, movement strategy, and user motivation.

Figure 1. *Illustration of the system environment.*

T Yamaguchi, P Richard, F Veaux, M Dinomais, S Nguyen, Upper-body interactive rehabilitation system for children with cerebral palsy: the effect of control/display ratios, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 181–186, Laval, France, 10 – 12 Sept. 2012.

Combining virtual reality and a myo-electric limb orthosis to restore active movement after stroke: a pilot study

S Bermúdez i Badia, E Lewis, S Bleakley

Universidade da Madeira, Funchal, PORTUGAL
Myomo Inc., Cambridge, MA, USA
University of Pittsburgh, PA, USA

ABSTRACT

We introduce a novel rehabilitation technology for upper limb rehabilitation after stroke that combines a virtual reality training paradigm with a myo-electric robotic limb orthosis. Our rehabilitation system is based on clinical guidelines and is designed to recruit specific motor networks to promote neuronal reorganization. The main hypothesis is that the restoration of active movement facilitates the full engagement of motor control networks during motor training. By using a robotic limb orthosis, we are able to restore active arm movement in severely affected stroke patients. In a pilot study, we have successfully deployed and evaluated our system with 3 chronic stroke patients by means of behavioral data and self-report questionnaires. The results show that our system is able to restore up to 60% of the active movement capacity of patients. Further, we show that we can assess the specific contribution of the biceps/triceps movement of the paretic arm to the virtual reality bilateral training task. Questionnaire data show enjoyment and acceptance of the proposed rehabilitation system and its VR training task.

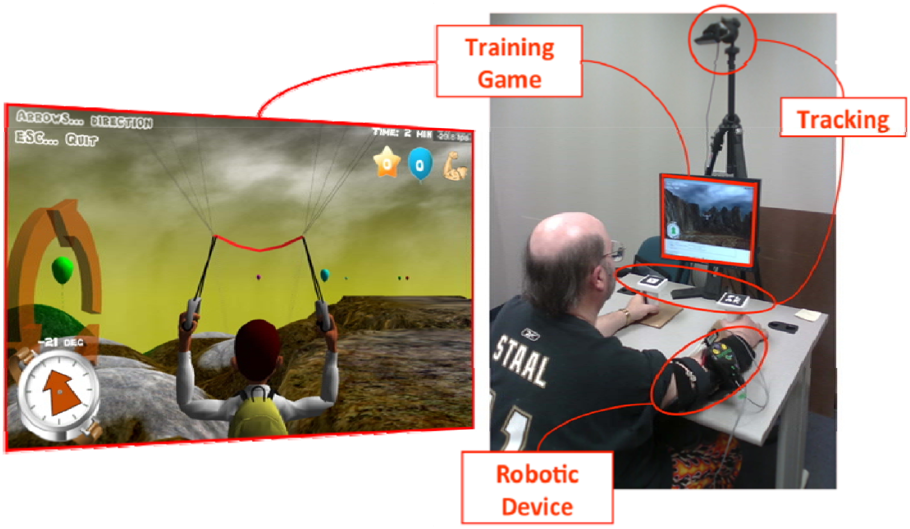


Figure 5. *Prototype of the myo-electric based interactive system for rehabilitation.*

S Bermúdez i Badia, E Lewis, S Bleakley, Combining virtual reality and a myo-electric limb orthosis to restore active movement after stroke: a pilot study, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 187–193, Laval, France, 10 – 12 Sept. 2012.

Serious games for physical rehabilitation: designing highly configurable and adaptable games

L Omelina, B Jansen, B Bonnechère, S Van Sint Jan, J Cornelis

Vrije Universiteit Brussel, Brussels, BELGIUM

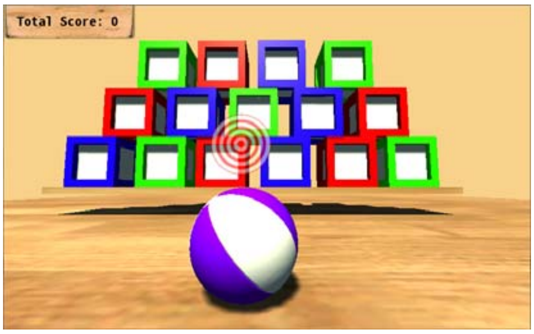
Interdisciplinary Institute for Broadband Technology, Ghent, BELGIUM

Université Libre de Bruxelles, Brussels, BELGIUM

ABSTRACT

Computer games have been recognized as a motivational tool in rehabilitation for a decade. Traditional rehabilitation includes exercises which are often considered as repetitive, boring and requires supervision by the therapist. New opportunities in rehabilitation have risen with the emerging popularity of computer games and novel input sensors like 3D cameras, balance boards or accelerometers. Despite active research in this area, there is still lack of available games for rehabilitation mainly due to many different requirements that have to be met for each type of therapy. In this paper we propose a specialized configurable architecture for revalidation games, focusing on neuro-muscular rehabilitation. The proposed architecture enables a therapist to define game controls depending on the patient needs and without any programing skills. We have also implemented a system meeting this architecture and four games using the system in order to verify correctness and functionality of the proposed architecture.

a)



b)

Figure 3. *a) Flying simulator game, b) HitTheBoxes game.*

L Omelina, B Jansen, B Bonnechère, S Van Sint Jan, J Cornelis, Serious games for physical rehabilitation: designing highly configurable and adaptable games, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 195–201, Laval, France, 10 – 12 Sept. 2012.

Session VI: Motor Rehabilitation

Developmental cognitive neuroscience perspective on motor rehabilitation: the case for virtual reality-augmented therapy

P H Wilson

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ABSTRACT

Developmental disorders and disabilities affecting movement can have far reaching, longer-term consequences for the child and their family, and present a great challenge for intervention. In the case of upper-limb function, in particular, poor compliance and use of repetitive training routines can restrict progress. In this paper we consider how an understanding of the neurocognitive bases of disorders like cerebral palsy and Developmental Coordination Disorder (DCD) can inform the choice of therapeutic techniques. Using a cognitive neuroscience approach, I explore the hypothesis that *motor prediction* is a common, underlying issue in these disorders. I then discuss the role that feedback-based and predictive control plays during the course of normal development and highlight recent applications of *augmented feedback* (AF) in motor therapy. Critically, VR-based technologies afford many options for the provision of multisensory AF. I describe recent examples of this principled approach to treatment, and conclude by suggesting avenues for future development in VR-assisted therapy.

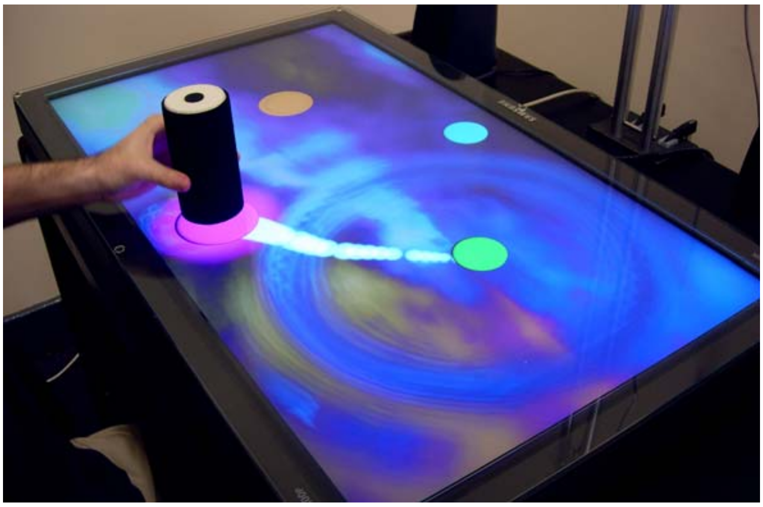

Figure 1. *Sample display from the Elements system: Goal-directed task including (visual) augmented feedback.*

P H Wilson, Developmental cognitive neuroscience perspective on motor rehabilitation: the case for virtual reality-augmented therapy, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 203–210, Laval, France, 10 – 12 Sept. 2012.

Assessing prospective memory in young healthy adults using virtual reality

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P Fleury, F Eustache, B Desgranges

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Université Paris Descartes, FRANCE

ABSTRACT

Virtual Reality (VR) is a very relevant tool for the study of complex cognitive functions, such as Prospective Memory (PM; remember to execute an intention at an appropriate time in the future). Thirty-five young subjects performed a PM task while immersed in a virtual city. On a theoretical level, we reached a better characterisation of PM functioning, notably regarding the influence of the link between the "when" and "what" components of PM on performance in event- and time-based PM tasks. This work validates utility of VR in PM assessment and opens perspectives in evaluation and rehabilitation of PM deficits.

Figure 1. *Virtual Environment: figure on the left displays caption of subjects' point of view during the experiment; figure on the right is an example of EBPM cue (i.e. buy a diary at the City Council).*

J Gonneaud, P Piolino, G Lecouvey, S Madeleine, E Orriols, P Fleury, F Eustache, B Desgranges, Assessing prospective memory in young healthy adults using virtual reality, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 211–218, Laval, France, 10 – 12 Sept. 2012.

Measuring the effect of affective stimuli on autonomic responses and task performance in a virtual environment by children with and without cerebral palsy

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Technion – Israel Institute of Technology, Haifa, ISRAEL

Bnai-Zion Medical Center, Haifa, ISRAEL

ABSTRACT

This study examined whether a functional virtual environment (VE) may be used to provide affective stimuli (AS) that lead to changes in the emotional responses and task performance of children with and without cerebral palsy (CP). Fifteen children with CP and 19 typically developing (TD) peers (6 to 12 years) prepared seven virtual meals in a predefined order within a virtual meal-making VE, referred to as the Emotional Meal-Maker (EMM), run on a 2D video capture VR platform. During each of six meals either a negative, positive, or neutral visual stimulus, selected from the International Affective Picture System (IAPS), was displayed. Heart rate (HR) and skin conductance (SCR) were recorded online in synchrony with stimulus onset. These variables were also recorded when the children passively viewed the same sequence of affective pictures displayed onscreen while rating their valence and arousal levels. Autonomic responses were calculated as the amount of change in the autonomic variables compared to baseline. Correlations between behavioural characteristics (i.e., trait and state anxiety) with both autonomic responses and task performance were also calculated. Significant differences were found between groups in task performance and heart rate variability (HRV) components, i.e., a higher "low frequency" (LF) to "high frequency" (HF) ratio in the children with CP during the meals in which a negative stimulus was displayed ($U= 59.00$, $p= 0.011$) and during the passive visual display, regardless of type of stimulus. For children with CP, the amplitude of skin conductance response during the passive pictures display was significantly higher for negative stimuli (0.80 ± 0.46 µS) than for positive stimuli (0.52 ± 0.28; $Z= -2.38$, $p= 0.017$), but there were no significant changes in autonomic responses as a function of stimuli during meal-making. Positive correlations were found in the CP group between trait anxiety and the LF:HF ratio during virtual meal-making with positive ($p< 0.05$) and negative stimuli ($p<0.01$) but not during meals when stimuli were neutral. The implications of these results are discussed.

S Kirshner, P L Weiss, E Tirosh, Measuring the effect of affective stimuli on autonomic responses and task performance in a virtual environment by children with and without cerebral palsy, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 219–228, Laval, France, 10 – 12 Sept. 2012.

Stress resilience in virtual environments: training combat relevant emotional coping skills using virtual reality

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ABSTRACT

The incidence of posttraumatic stress disorder (PTSD) in returning OEF/OIF military personnel has created a significant behavioral healthcare challenge. This has served to motivate research on how to better develop and disseminate evidence-based treatments for PTSD. One emerging form of treatment for combat-related PTSD that has shown promise involves the delivery of exposure therapy using immersive Virtual Reality (VR). Initial outcomes from open clinical trials have been positive and fully randomized controlled trials are currently in progress to further investigate the efficacy of this approach. Inspired by the initial success of this research using VR to emotionally engage and successfully treat persons undergoing exposure therapy for PTSD, our group has begun developing a similar VR-based approach to deliver stress resilience training with military service members prior to their initial deployment. The STress Resilience In Virtual Environments (STRIVE) project aims to create a set of combat simulations (derived from our existing Virtual Iraq/Afghanistan PTSD exposure therapy system) that are part of a multi-episode interactive narrative experience. Users can be immersed within challenging combat contexts and interact with virtual characters within these episodes as part of an experiential learning approach for delivering psychoeducational material, stress management techniques and cognitive-behavioral emotional coping strategies believed to enhance stress resilience. The STRIVE project aims to present this approach to service members prior to deployment as part of a program designed to better prepare military personnel for the types of emotional challenges that are inherent in the combat environment. During these virtual training experiences users are monitored physiologically as part of a larger investigation into the biomarkers of the stress response. One such construct, Allostatic Load, is being directly investigated via physiological and neuro-hormonal analysis from specimen collections taken immediately before and after engagement in the STRIVE virtual experience. This paper describes the development and evaluation of the Virtual Iraq/Afghanistan Exposure Therapy system and then details its current transition into the STRIVE tool for pre-deployment stress resilience training. We hypothesize that VR stress resilience training with service members in this format will better prepare them for the emotional stress of a combat deployment and could subsequently reduce the later incidence of PTSD and other psychosocial health conditions.

A A Rizzo, B John, J Williams, B Newman, S T Koenig, B S Lange, J G Buckwalter, Stress resilience in virtual environments: training combat relevant emotional coping skills using virtual reality, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 229–237, Laval, France, 10 – 12 Sept. 2012.

Towards a real-time, configurable, and affordable system for inducing sensory conflicts in a virtual environment for post-stroke mobility rehabilitation: vision-based categorization of motion impairments

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Toronto Rehabilitation Institute, CANADA

ABSTRACT

Upper body motion impairment is a common after-effect of a stroke. A virtual reality system is under development that will augment an existing intervention (Mirror Box therapy) with a method of inducing a body illusion (Rubber Hand) in order to enhance rehabilitation outcomes. The first phase of the project involved developing algorithms to automatically differentiate between normal and impaired upper body motions. Validation experiments with seven healthy subjects simulating two common types of impaired motions confirm the effectiveness of the proposed methods in detecting impaired motions (accuracy >95%).

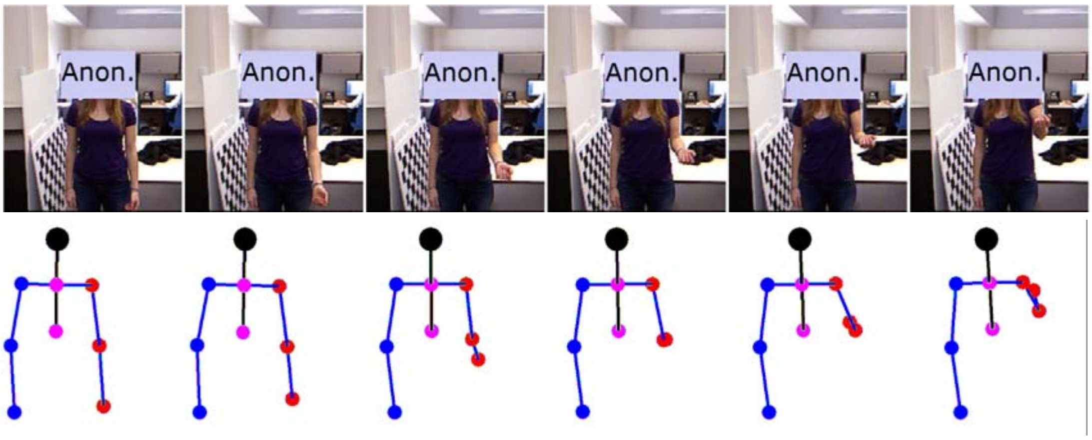

Figure 6. *Sample color, depth, and skeleton tracking images in six representative frames over two sequences of elbow flexion. The top three rows illustrate a "normal" movement pattern while the bottom three rows illustrate a simulated "impaired" motion synergy of hiking the shoulder when flexing the elbow, common among the post-stroke population.*

B Taati, J Campos, J Griffiths, M Gridseth, A Mihailidis, Towards a real-time, configurable, and affordable system for inducing sensory conflicts in a virtual environment for post-stroke mobility rehabilitation: vision-based categorization of motion impairments, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Tech.*, P M Sharkey, E Klinger (Eds), pp. 239–244, Laval, France, 10 – 12 Sept. 2012.

Session VIII: Design & Analysis

User-centered development of a virtual reality cognitive assessment

S T Koenig, D Krch, N Chiaravalloti, J Lengenfelder,
O Nikelshpur, B S Lange, J DeLuca, A A Rizzo

USC Institute for Creative Technologies, Playa Vista, CA, USA

Kessler Foundation Research Center, West Orange, NJ, USA

ABSTRACT

In recent years user-centered design, participatory design and agile development have seen much popularity in the field of software development. More specifically, applying these methods to user groups with cognitive and motor disabilities has been the topic of numerous publications. However, neuropsychological assessment and training require special consideration to include therapists and brain-injured patients into the development cycle. Application goals, development tools and communication between all stakeholders are interdependent and outlined in a framework that promotes elements of agile development. The framework is introduced by example of a virtual reality cognitive assessment for patients with traumatic brain injuries. The assessment has seen a total of 20 iterations over the course of nine months including changes in task content, task difficulty, user interaction and data collection. The framework and development of the cognitive assessment are discussed.

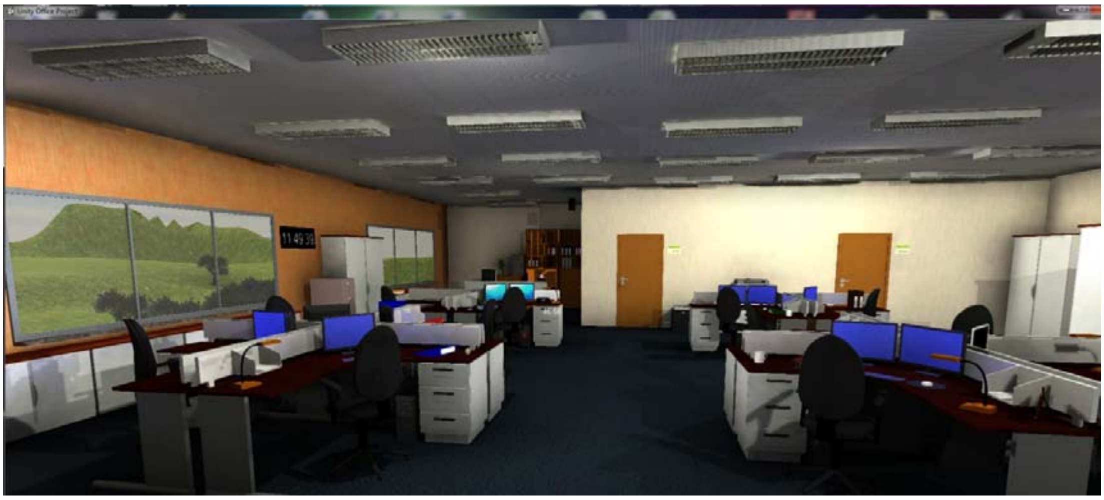

Figure 2. *Virtual office environment rendered in the Unity game engine*

S T Koenig, D Krch, N Chiaravalloti, J Lengenfelder, O Nikelshpur, B S Lange, J DeLuca, A A Rizzo, User-centered development of a virtual reality cognitive assessment, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 247–253, Laval, France, 10 – 12 Sept. 2012.

Session VIII: Design & Analysis

User perspectives on multi-touch tabletop therapy

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ABSTRACT

Technology-based activities are becoming increasingly popular in therapy programs. In particular, multi-touch tabletops seem to be well suited for many therapy activities. To better understand the benefits of using multi-touch tabletops during rehabilitation, we examined users' attitudes towards rehabilitation activities on a multi-touch tabletop and on a non-interactive surface. Using a standardized questionnaire and semi-structured interviews, we identified many advantages and limitations of using multi-touch tabletops in rehabilitation. We discuss the implications of user expectations and experiences on the design of future activities.

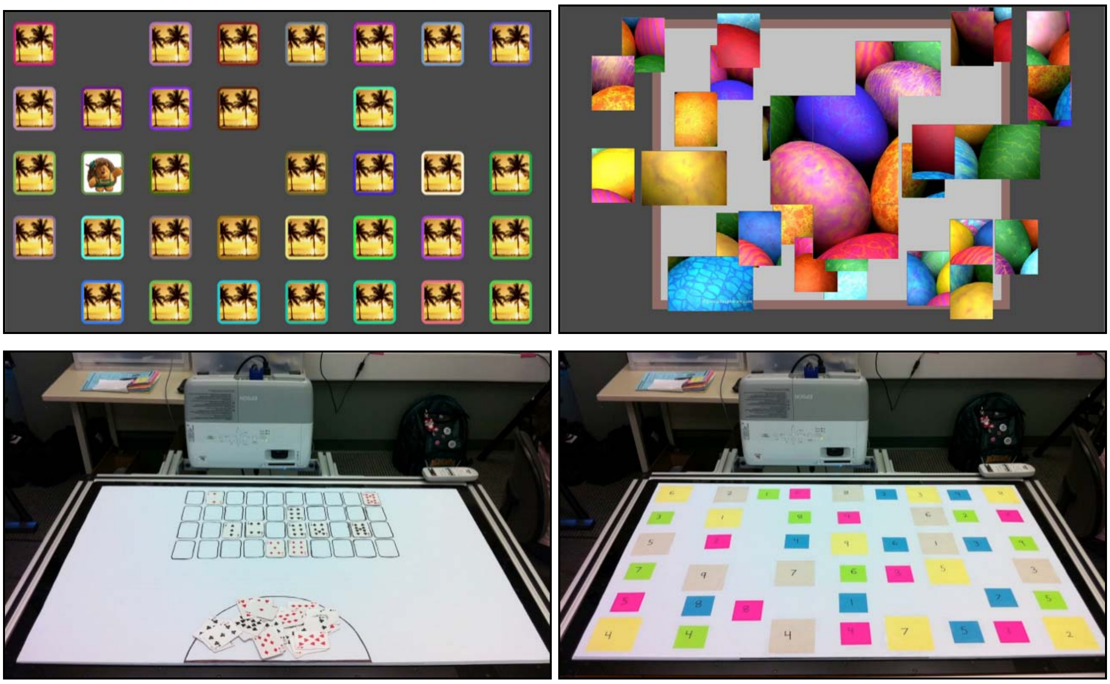

Figure 1. *(Clockwise from top left) The four activities used in the study: Memory (in which participants touched virtual tiles to 'flip them' and reveal images underneath that must be matched), Puzzle (in which participants had to slide tiles on the screen to assemble a large picture), Card Sorting (in which participants had to slide physical cards into ascending order, by suit, onto the grid) and Grid of Stickers (in which participants repeatedly touched the tiles in order, by color).*

M Annett, F Anderson, W F Bischof, User perspectives on multi-touch tabletop therapy, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 255–260, Laval, France, 10 – 12 Sept. 2012.

Development of a complex ecological virtual environment

S Sangani, P L Weiss, R Kizony, S T Koenig, M F Levin, J Fung

McGill University, Montreal, CANADA
Jewish Rehabilitation Hospital, Laval, Quebec, CANADA
University of Haifa, ISRAEL
Sheba Medical Center, Tel Hashomer, ISRAEL
USC Institute for Creative Technologies, Playa Vista, CA, USA

ABSTRACT

Virtual environments (VEs) provide clinicians and researchers an opportunity to develop and implement an engaging, ecologically valid, complex, life-like interactive 3D simulation, which can be tailored dynamically to characterize and precisely measure functional behaviour in response to different multisensory stimuli. Complex ecological VEs that are based on familiar real-world environments enable participants to relate to the training environment which in turn, may promote translation of functional improvements to real-world tasks. This study describes the development of a systematic and context-specific complex VE using simple computer graphics and modelling tools.

Figure 6. *The virtual environment (right) closely resembled the real environment (left).*

S Sangani, P L Weiss, R Kizony, S T Koenig, M F Levin, J Fung, Development of a complex ecological virtual environment, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 261–268, Laval, France, 10 – 12 Sept. 2012.

Collaborative virtual environment for conducting design sessions with students with autism spectrum conditions

L Millen, S V G Cobb, H Patel, T Glover

University of Nottingham, UK

ABSTRACT

Young students with autism spectrum conditions (ASC) often find it difficult to communicate with others face-to-face. Virtual reality offers a platform in which students can communicate in a safe and predictable environment where face-to-face communication is not necessary. Participatory design with end-users is an important part of developing successful, usable and enjoyable technology. As designers of technology for young students with ASC, we seek to involve these end-users in the design of software. Therefore, we have developed the Island of Ideas: a collaborative virtual environment (CVE) designed to facilitate participatory design activities with students with ASC. In this paper we report an experimental trial of the Island of Ideas CVE as a meeting space in which a researcher talks with students to find out their views on computer game design and their ideas for new game levels.

Figure 1 (left). *The Island of Ideas CVE.* **Figure 2** (right). *A student and researcher accessing the CVE from separate laptops (Images blurred to protect student identity).*

L Millen, S V G Cobb, H Patel, T Glover, Collaborative virtual environment for conducting design sessions with students with autism spectrum conditions, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 269–278, Laval, France, 10 – 12 Sept. 2012.

Development of a low-cost virtual reality-based smart glove for rehabilitation

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ABSTRACT

Presented is the third version of a low-cost bimanual rehabilitation system designed for in-home use by post stroke patients to improve hand and upper extremity function. Companion virtual reality software is still in development. The mechanical characterization and healthy subject (n=24) testing of the system sensors is described. These sensors include potentiometer bend sensors for finger motions and inertial measurement units (IMUs) for hand/arm position and orientation. The system accurately measures larger finger angles and all functional ranges of hand orientation (yaw, pitch, roll). Measurement of small finger angles and position of the hand in space requires further refinement.

Figure 1. *ATLAS bimanual glove system.*

M Sivak, D Murray, L Dick, C Mavroidis, M K Holden, Development of a low-cost virtual reality-based smart glove for rehabilitation, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 279–286, Laval, France, 10 – 12 Sept. 2012.

What are the current limits of the Kinect™ sensor?

B Bonnechère, B Jansen, P Salvia, H Bouzahouene, L Omelina,
J Cornelis, M Rooze, S Van Sint Jan

Université Libre de Bruxelles, Brussels, BELGIUM
Vrije Universiteit Brussel, Brussels, BELGIUM
Interdisciplinary Institute for Broadband Technology, Ghent, BELGIUM

ABSTRACT

The Kinect sensor offers new perspectives for the development and application of affordable, portable and easy-to-use markerless motion capture (MMC) technology. However, at the moment, accuracy of this device is still not known. In this study we compare results from Kinect (MMC) with those of a stereophotogrammetric system (marker based system [MBS]). 27 subjects performed a deep squatting motion. Parameters studied were segments lengths and joint angles. Results varied significantly depending on the joint or segment analysed. For segment length MMC shows poor results when subjects were performing movement. Differences were also found concerning joint angles, but regression equations were computed for each joint that produced the same results for MMC and MBS after correction.

Table 3. *Kinect Results before and after correction.*
Difference = Kinect Processed - Vicon
** correlation is significant at percentile 0.01 α p=0.05.*

Articulation	Kinect	*Kinect Processed*	Vicon	Difference	P	R
Shoulder	58 (18)	***58 (15)***	58 (16)	0 (6)	0.94	0.93*
Elbow	40 (26)	***30 (10)***	29 (15)	1 (17)	0.75	0.28
Wrist	35 (19)	***19 (5)***	18 (9)	0 (9)	0.92	0.33
Hip	73 (17)	***78 (14)***	78 (16)	0 (7)	0.98	0.94*
Knee	107 (27)	***106 (23)***	107 (22)	-1 (14)	0.78	0.88*
Ankle	90 (36)	***29 (2)***	29 (8)	0 (8)	0.99	0.53*
Trunk	50 (10)	***39 (8)***	39 (16)	0 (16)	0.91	0.45*

B Bonnechère, B Jansen, P Salvia, H Bouzahouene, L Omelina, J Cornelis, M Rooze, S Van Sint Jan, What are the current limits of the Kinect™ sensor?, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 287–294, Laval, France, 10 – 12 Sept. 2012.

Virtual reality learning software for individuals with intellectual disabilities: comparison between touchscreen and mouse interactions

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ABSTRACT

The aim of this article is to analyze the impact of two user interfaces - a tactile interface and a computer mouse - on a virtual environment allowing self-learning tasks as dishwashing by workers with mental deficiencies. We carried out an experiment within the context of a design project named “Apticap”. The methods used were an experiment, an identification questionnaire and a post-experimentation interview, with six disabled workers. The results of this study demonstrate the interest of a virtual reality tool associated with a tactile interaction for learning of real tasks by workers with mental deficiencies.

Figure 1. *Reception of dirty dishes.*

E Loup-Escande, O Christmann, R Damiano, F Hernoux, S Richir, Virtual reality learning software for individuals with intellectual disabilities: comparison between touchscreen and mouse interactions, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 295–303, Laval, France, 10 – 12 Sept. 2012.

Session IX: Interfacing to Virtual Environments

Development of a glove-type input device with the minimum number of sensors for Japanese finger spelling

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Kyoto University Hospital, JAPAN

ABSTRACT

A glove-type input device, which can measure hand postures of human beings directly, is one of essential device to develop Virtual Reality environment. The authors have been developing a data-glove which would be able to capture hand postures according to user's demand with the minimum number of sensors. Our previous research estimated the data-glove with six sensors could measure all hand postures for Japanese Finger spellings. Thus, this paper proposes a prototype with six sensors and evaluate whether the prototype glove sensor can distinguish all hand postures of Japanese Finger spellings. This evaluation indicated that data-glove with fewer sensors than conventional number of sensors could distinguish hand postures exactly.

Figure 3. *Sensor Layout(left) and the prototype(right).*

Y Tabata, T Kuroda, K Okamoto, Development of a glove-type input device with the minimum number of sensors for Japanese finger spelling, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 305–310, Laval, France, 10 – 12 Sept. 2012.

Camera-based software as a significant tool in rehabilitation/therapy intervention

A L Brooks

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ABSTRACT

Use of an affordable, easily adaptable, 'non-specific camera-based software' that is rarely used in the field of rehabilitation is reported in a study with 91 participants over the duration of six workshop sessions. 'Non-specific camera-based software' refers to software that is not dependent on specific hardware. Adaptable means that human tracking and created artefact interaction in the camera field of view is relatively easily changed as one desires via a user-friendly GUI. The significance of having both available for contemporary intervention is argued. Conclusions are that the mature, robust, and accessible software EyeCon is a potent and significant tool in the field of rehabilitation/therapy and warrants wider exploration.

Figure 4. *EyeCon (left screen) plus Eyesweb (right screen) software (split camera feed) - Dynamic zones (rectangles) that are mapped to rhythm music loops and digital painting.*

A L Brooks, Camera-based software as a significant tool in rehabilitation/therapy intervention, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 311–316, Laval, France, 10 – 12 Sept. 2012.

Augmented reflection technology for stroke rehabilitation – a clinical feasibility study

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ABSTRACT

This paper presents a clinical feasibility study of a novel Augmented Reflection Technology system, called TheraMem. The feasibility of the system for physical rehabilitation of the upper limb and the potential to improve motor impairments following stroke were evaluated. Five patients participated in a total of 20 sessions of upper limb training with the system. Tailored support for patients performing the exercises was provided based on the severity and level of their impairment. Various configurations of the system were evaluated and adjusted to best match the patient's preferences as well as the therapeutic requirements. We found that all patients were able to successfully participate and complete the TheraMem intervention. Patients' engagement and motivation was high over the course of the therapy sessions.

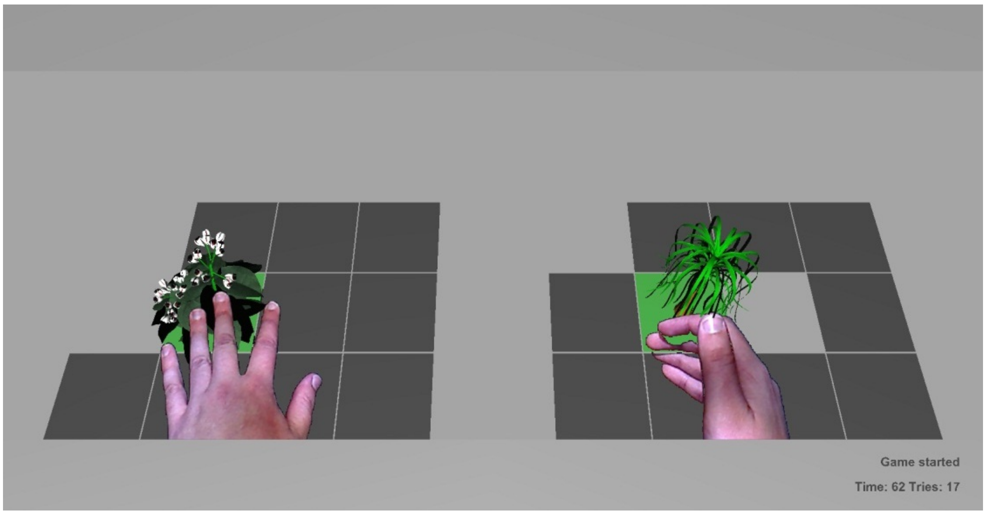

Figure 7. *Gameplay of TheraMem for a patient with an impaired right hand.*

S Hoermann, L Hale, S J Winser, H Regenbrecht, Augmented reflection technology for stroke rehabilitation – a clinical feasibility study, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 317–322, Laval, France, 10 – 12 Sept. 2012.

Telerehabilitation for stroke patients: an overview of reviews

A Turolla, L Piron, T Gasparetto, M Agostini, H R Jorgensen, P Tonin, T Larsen

IRCCS Fondazione Ospedale San Camillo, Venice, ITALY

Social and Health Programs, Regione Veneto, Venice, ITALY

Sygheus Vendsyssel Brønderslev Neurorehabiliteringscenter, Brønderslev, DENMARK

Southern Denmark University, Odense, DENMARK

ABSTRACT

The increasing number of survivors following stroke events are enlightening new needs to guarantee appropriate care and quality of life support at home. A potential application of telemedicine is to exploit home care and rehabilitation. Within the framework of an EU FP7 project called Integrated Home Care (IHC) we performed an overview of reviews on the telefacilites for the homecare in stroke patients, in order to plan a clinical trial. A broad literature research was conducted in PUBMED, Web of Science® and The Cochrane Library databases. We included and graded all the reviews matching the following criteria: published in English in peer-reviewed journals, targeting stroke as adult patients (age>18yr.) and considering a homecare setting in the intervention. 6 full-text reviews were included: 1 systematic review with meta-analysis and 5 non-systematic reviews. Despite the absence of adverse effects, no conclusions can be stated on the effectiveness of telerehabilitation compared to other home treatment, due to the insufficient data available, nevertheless strong indications emerged for the inclusion of "all cause mortality" and "hospital admission" as primary outcomes. Besides "QoL", "cost", "adherence" and "patient acceptability" should be included as secondary outcomes, for a complete evaluation of the tele-intervention. This indications should be considered as relevant in planning a telerehabilitation trial, in order to observe the expected effectiveness from a multidimensional point of view in the clinical, financial and social perspectives.

A Turolla, L Piron, T Gasparetto, M Agostini, H R Jorgensen, P Tonin, T Larsen, Telerehabilitation for stroke patients: an overview of reviews, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 323–328, Laval, France, 10 – 12 Sept. 2012.

Information and communication technology – a person-centered approach to stroke care

J Broeren, J Jalminger, L-Å Johansson, A Parmerud, L Pareto, M Rydmark

Sahlgrenska University Hospital, Västra Götaland County, SWEDEN
Alkit Communications, Mölndal, SWEDEN
University West, Trollhättan, SWEDEN
The Sahlgrenska Academy, University of Gothenburg, SWEDEN

ABSTRACT

This report describes the possibilities of information and communication technology (ICT) in stroke care, addressing a person-centered care (PCC) approach. Attention is paid to user involvement, design, videogames, and communication between health care professionals mutually as well as with patients, and how to share performance data with an electronic health record. This is the first step towards a supportive ICT system that facilitates interoperability, making healthcare information and services available to citizen's across organizational boundaries.

Figure 1. *A screenshot from the player's perspective, in the upper left corner reaching for a red box (black circle) and at the bottom right corner a blue box (dotted circle) flies in.*

J Broeren, J Jalminger, L-Å Johansson, A Parmerud, L Pareto, M Rydmark, Information and communication technology – a person-centered approach to stroke care, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 329–335, Laval, France, 10 – 12 Sept. 2012.

Second-hand masculinity: do boys with intellectual disabilities use computer games as part of gender practice?

D Charnock, P J Standen

University of Nottingham, Nottingham, UK

ABSTRACT

The process of gendered practice in the pursuit of masculine identity is complex with many obstacles and hegemonic forms to negotiate on the journey. Add to this the multifaceted and diverse nature of intellectual disability (ID) and the opportunity for normalised gendered practice is further complicated. Focused on the talk of boys with ID, this paper offers an account of the development of ideas about masculinity to show how gaming may offer a space for gendered practice not available in other areas of the boys' lives. The paper tentatively argues that gaming may offer an opportunity for the boys and those working with them to explore gendered practice safely to facilitate the construction of their identities as men and to challenge problematic images of the hyper-masculine ideal found in these games.

D Charnock, P J Standen, Second-hand masculinity: do boys with intellectual disabilities use computer games as part of gender practice?, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 337–344, Laval, France, 10 – 12 Sept. 2012.

Session XI: Training & Assessment II

Using virtual environments to teach coping skills in addiction treatment

L North, C Robinson, A Haffegee, P M Sharkey, F Hwang

Swanswell, Rugby, UK
University of Reading, UK

ABSTRACT

This paper presents a novel application of virtual environments to assist in encouraging behaviour change in individuals who misuse drugs or alcohol. We discuss the background and development, through user-led design, of a series of scenes to engage users around the identification of triggers and encourage discussion about relevant coping skills. We then lay out the results of some initial testing of this application that show some positive reaction to the scenes and some positive learning outcomes and discuss the conclusions drawn from these.

Figure 1. *Identifying triggers in a virtual bar.*

L North, C Robinson, A Haffegee, P M Sharkey, F Hwang, Using virtual environments to teach coping skills in addiction treatment, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 345–353, Laval, France, 10 – 12 Sept. 2012.

Virtual reality exposure therapy for post-traumatic stress disorder patients controlled by a fuzzy logic system

F M de Oliveira, R S Lanzillotti, R M E M da Costa, R Gonçalves,
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Universidade Federal do Rio de Janeiro, BRAZIL

ABSTRACT

This paper describes the main characteristics of two integrated systems that explore Virtual Reality technology and Fuzzy Logic to support and to control the assessment of people with Post-Traumatic Stress Disorder during the Virtual Reality Exposure Therapy. The integration of different technologies, the development methodology and the test procedures are described throughout the paper.

Figure 2: *The scene of an accident: a person was hit by a bus.*

F M de Oliveira, R S Lanzillotti, R M E M da Costa, R Gonçalves, P Ventura, L A V de Carvalho, Virtual reality exposure therapy for post-traumatic stress disorder patients controlled by a fuzzy logic system, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 355–360, Laval, France, 10 – 12 Sept. 2012.

Session XII: Cognitive Rehabilitation II

Virtual exercises to promote cognitive recovery in stroke patients: the comparison between head mounted displays versus screen exposure methods

P Gamito, J Oliveira, N Santos, J Pacheco, D Morais, T Saraiva,
F Soares, C SottoMayor, A F Barata

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Alcoitão Hospital, Alcabideche, PORTUGAL

ABSTRACT

Stroke can be considered as a major cause of death and the consequences are associated with different syndromes of the impaired physical, cognitive, behavioral and emotional domains. The cognitive rehabilitation is often related to improvement on executive functioning through repeated and systematic training in memory and attention exercises, in which virtual reality has proven to be a valid approach. Several devices have been used as visual outputs. Head mounted displays (HMD) and desktop screens displays are amongst them. HMD is usually perceived has being more immersive than screens. However, it presents several shortcomings if a widespread use is the objective. In this way, this study aims at assessing the prospect of opting for screen displays as an alternative to HMD within virtual reality (VR) based applications to rehabilitate memory and attention impairments in stroke patients. A sample of 17 patients with memory and attention deficits resulting from stroke were recruited from the hospital *Centro de Medicina da Reabilitação do Alcoitão*. The patients were randomly assigned to two different groups: (1) HMD based VR; and (2) desktop screen based VR. The patients in the experimental groups underwent a virtual reality (VR) training programme with 12 sessions regarding memory and attention exercises. These patients were assessed before and after the VR training sessionswith the Wechsler Memory Scale for memory and the Toulouse Pieron for attention functioning. The results showed increased working memory and sustained attention from initial to final assessment regardless of the VR device used. These data may suggest better functional independence following VR-based intervention and support the use of non-expensive displays as an alternative to high-end setups commonly used in VR applications devised for rehabilitation purposes.

P Gamito, J Oliveira, N Santos, J Pacheco, D Morais, T Saraiva, F Soares, C SottoMayor, A F Barata, Virtual exercises to promote cognitive recovery in stroke patients: the comparison between head mounted displays versus screen exposure methods, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 361–367, Laval, France, 10 – 12 Sept. 2012.

Design of virtual reality based physical and cognitive stimulation exercises for elderly people

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Arts et Métiers ParisTech, Laval, FRANCE

CIGMA, CIDEVIM, Laval, FRANCE

ABSTRACT

Elderly people are the most growing part of the population in developed countries (Europe, North America and Japan). This population is getting more and more alone and isolating this part of the population is the big issue of this century. This isolation can lead to a lack in physical and cognitive activity. Because virtual reality has given good results in health domain, we decided to design an application that combines physical activities and cognitive stimulation. The "Balade à l'EHPAD" application was then tested on different kind of population. Then, the expectations and needs of elderly people were collected and analyzed. The results clearly indicate that preconceived ideas exist in every people and also in professional caregivers who generally have a better knowledge of this population. Elderly people would like to have raw colors and virtually practice more violent sports (*e. g.*, skiing, rugby). The overall study clearly indicates that more than for younger adults, the involvement of elderly people into the application design process is a prerequisite for the appropriation by this population.

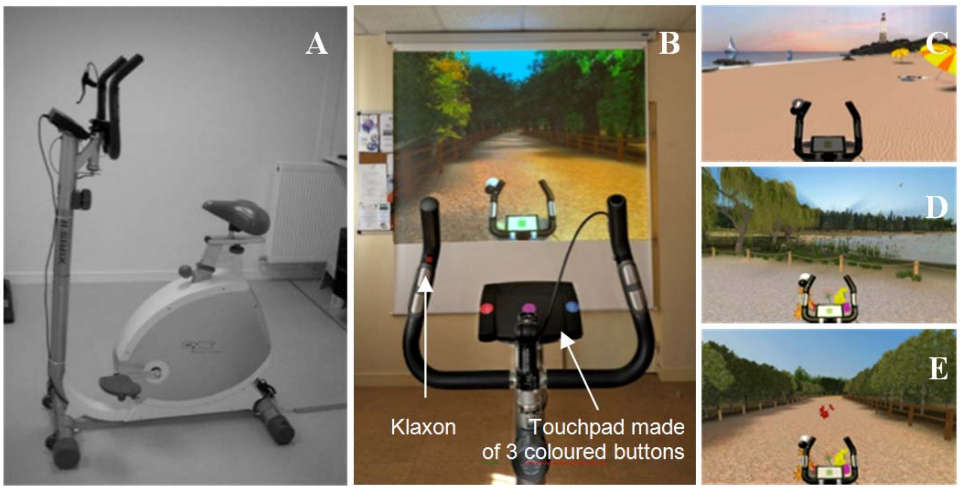

Figure 8. *"Balade à l'EHPAD" provides an interfaced bike (A) for a virtual bike ride (B) in two different environments: the seaside (C) and a forest (D). The participants are suggested to be involved in simple cognitive exercises as collecting flowers (E).*

E Klinger, E Martinet, A L Lucas, D Perret, Design of virtual reality based physical and cognitive stimulation exercises for elderly people, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 369–377, Laval, France, 10 – 12 Sept. 2012.

Session XII: Cognitive Rehabilitation II

Study of the impact of added contextual stimuli on the performance in a complex virtual task among patients with brain injury and controls

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EA4136, Bordeaux, FRANCE

ABSTRACT

During the last years, researchers showed the feasibility and the interest of using Virtual Reality (VR) among patients with cognitive impairments for the recovery of capacities. While interacting, the VR system provides various kinds of information for different purposes: display of the virtual environment, understanding of the task, but also highlighting of functionalities or delivery of instructions. Generally, in order to improve the patient performance, additional cues are provided to enhance information saliency, such as arrows, change of colors. We define a "contextual Additional Software Stimulus" (contextual ASS) as any additional information delivered by the virtual system, related to the interaction whose absence in the virtual environment does not have an effect on the unfolding of the task. This work was designed to study the effects of contextual ASS on the performance in a daily living simulated task: purchasing items in the Virtual Action Planning Supermarket (The VAP-S). In this purpose, we started by implementing ASS in the VAP-S then we carried out experiments in which 23 healthy subjects (12 M and 11F) and 12 patients with brain injury (12 M) took part. Results show that the deliverance of contextual ASS during the virtual task improves significantly some parameters describing the performance of healthy subject and patients with brain injury.

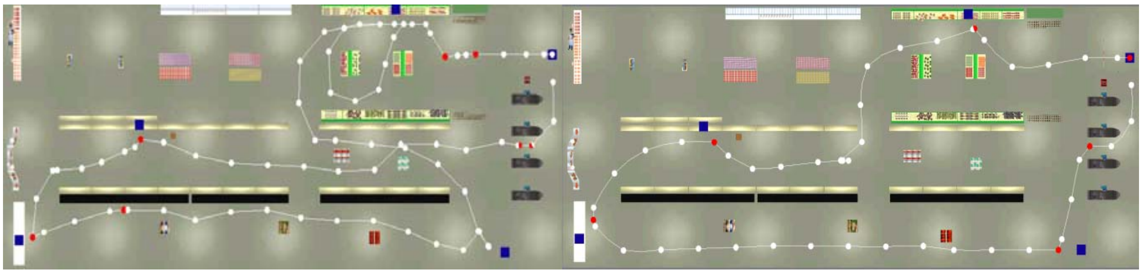

Figure 9. *Two examples of curves representing two trajectories of a subject in the conditions C0 (on the left) and C2 (on the right).*

H Cherni, P-A Joseph, E Klinger, Study of the impact of added contextual stimuli on the performance in a complex virtual task among patients with brain injury and controls, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 379–384, Laval, France, 10 – 12 Sept. 2012.

Session XII: Cognitive Rehabilitation II

Development of the system for continuous medical rehabilitation for patients with post-stroke and spinal cord injury motor disorders

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Siberian Clinical Center FMBA, Krasnoyarsk, RUSSIA

ABSTRACT

This paper describes an experience of developing a computer system for continuous medical rehabilitation involving patients with post-stroke and spinal cord injury motor disorders. Particular focus is made on the concept of telerehabilitation for this specific group of patients. Telerehabilitation has to be continuous and regular. It is also necessary to provide the possibility of conducting treatment/communication sessions asynchronously. The empirical results of four year implementation of this system in Russia showed high efficiency and revealed some limitations of a distant network rehabilitation program based on electromyographic biofeedback.

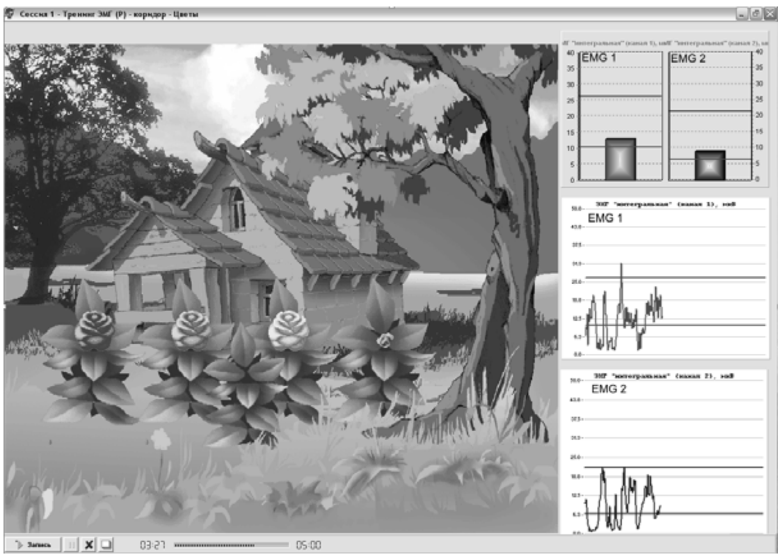

Figure 3. *Screenshot of a game form of EMG biofeedback. If both signals (EMG1 and EMG2) lie in the range between the thresholds in so called target zone a flower grows and blooms.*

O A Jafarova, E A Tarasov, R Yu Guk, M B Shtark, Development of the system for continuous medical rehabilitation for patients with post-stroke and spinal cord injury motor disorders, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 385–392, Laval, France, 10 – 12 Sept. 2012.

Session XIII: Visual Impairment II

Improving orientation and mobility skills through virtual environments for people who are blind: past research and future potential

O Lahav

Tel-Aviv University, ISRAEL

ABSTRACT

This presented paper describes and examines 21 virtual environments developed specifically to support people who are blind in collecting spatial information before arrival at a new location and to help people who are newly blind practice orientation and mobility skills during rehabilitation. The paper highlights weaknesses and strengths of virtual environments that have been developed in the past 15 years as orientation and mobility aids for people who are blind. These results have potential to influence future research and development of a new orientation and mobility aid that could enhance navigation abilities.

O Lahav, Improving orientation and mobility skills through virtual environment for people who are blind: past research and future potential, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 393–398, Laval, France, 10 – 12 Sept. 2012.

Development of a visual impairment simulator using the Microsoft XNA Framework

J Lewis, L Shires, D J Brown

Nottingham Trent University, UK

ABSTRACT

This paper describes the development of a visual impairment simulator based upon a virtual environment developed using Microsoft's XNA framework and High Level Shader Language. Shaders were developed to simulate the effects of cataracts, macular degeneration, glaucoma, myopia and hyperopia. These were then used to impair the real time display of an explorable 3D virtual environment. The simulator was evaluated by a qualified optician and trialled with a group of students. The paper concludes that further development is required to fully and accurately represent the impairments, however the simulator remains effective in improving participants level of understanding of visual impairments.

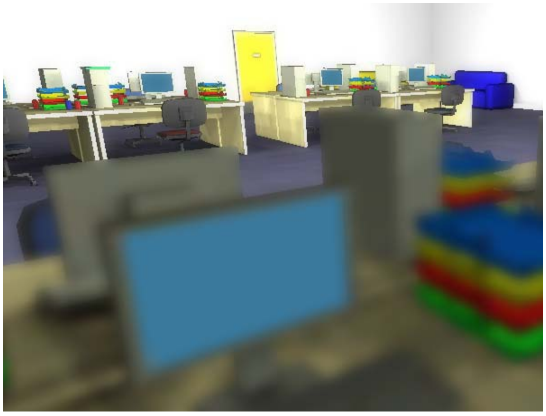

Figure 6. *Implementation of hyperopia.*

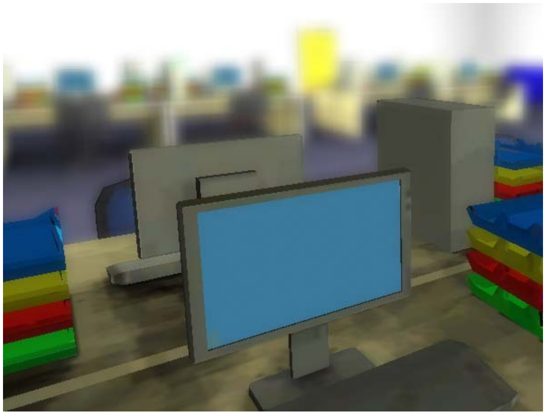

Figure 7. *Implementation of myopia.*

J Lewis, L Shires, D J Brown, Development of a visual impairment simulator using the Microsoft XNA Framework, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 399–407, Laval, France, 10 – 12 Sept. 2012.

Chilean higher education entrance examination for learners who are blind

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University of Chile, Santiago, CHILE

ABSTRACT

In the context of the admissions process for Chilean state universities, there is a knowledge-measuring instrument called the University Selection Test (PSU, for its Spanish acronym). This instrument of evaluation is designed to measure the level of knowledge in various learning sub-sectors such as Language and Communication, Mathematics, History and Social Sciences, and finally Science. For each learning sub-sector, students use a paper facsimile with questions that each have 5 possible answer choices, which are recorded on a separate answer sheet. Based on a contextual analysis of the problems that people who are blind have with participating in the regular admissions process for Chilean universities, the purpose of this study was to design, implement and evaluate a digital pilot system that adapts the Chilean university entrance system, PSU, in the area of Language in Communication for people with disabilities based on audio and haptics. This pilot allowed for the inclusive, equitable and autonomous participation of people with visual disabilities in the university admissions processes. The results demonstrate the creation of a system called AudioPSU, which provides the necessary autonomy and respects the working time that each user needs to respond to the questions in the PSU. In addition, the system is shown to help users to map the structure of the PSU facsimile for Language and Communication. Finally, initial results show that AudioPSU allows for the integration of people with visual disabilities in the admissions process for Chilean universities.

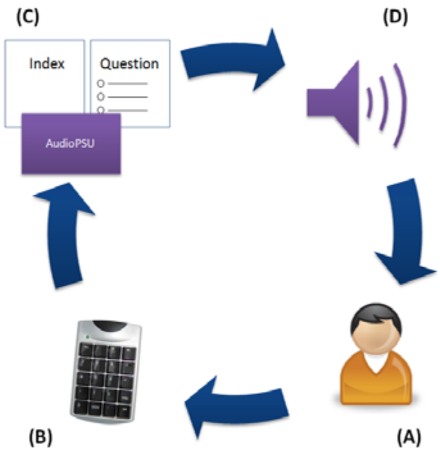

Figure 3. *The User's Interaction with AudioPSU.*

J Sánchez, M Espinoza, Chilean higher education entrance examination for learners who are blind, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 409–418, Laval, France, 10 – 12 Sept. 2012.

Short Papers ~ Abstracts

Novel electronic musical instrument for persons with cerebral palsy to play and enjoy together, **K Akazawa**, **T Kawai**, **R Okuno**, **T Masuko**, **H Nishida**, **M Horai**, Osaka Institute of Technology/Setsunan University, Osaka-fu/ Mukogawa Women's University, Hyogo-ken/SANYO Electric Co., Ltd., Osaka-fu/Social Welfare Organization Kibounoie Takarazuka, Hyogo-ken, JAPAN

We have developed a novel musical instrument with storing pre-programmed music score in PC, named Cyber Musical Instrument with Score, "Cymis". Using Cymis, persons with neural or motor impairments such as cerebral palsy can play the piece easily. This instrument consists of monitor display, PC, MIDI sound source, speaker and interfaces, such as touch panel, switch and expiratory pressure sensing device. The field experiment commenced in 2008, and at present, ten facilities including National Hospital participate in the experiment. Assessment scales are constructed with 5 levels from 0 (almost no disability) to 4 (almost immobile)，corresponding to the performing devices such as single input device to complex touch panel input method. Assessment was recorded during 27 months from Jan. 2009 to March 2011 in a facility. Results obtained from 44 clients (average age: 54.6) were as follows; no change of level was 24 (55%), dropped 1 level (improved functionally) was 19 (43%), up 1 level (decline functionally) was 1 (2 %). In conclusion, this paper presents the technology that is designed to be attractive to clients, that permits them to do an enjoyable activity that may not otherwise be possible for them, and that has shown some evidence to therapeutic effect.

K Akazawa, T Kawai, R Okuno, T Masuko, H Nishida, M Horai, Novel electronic musical instrument for persons with cerebral palsy to play and enjoy together, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 419–422, Laval, France, 10 – 12 Sept. 2012.

Virtual rehabilitation system for people with Parkinson's disease, **S Albiol-Pérez**, **J A Lozano-Quilis**, **H Gil-Gómez**, **J A Gil-Gómez**, **R Llorens**, Universidad de Zaragoza, Teruel/Universitat Politècnica de València, SPAIN

Patients that suffer from Parkinson's disease (PD) have different symptoms such as tremors, stiffness and slowness in the execution of first movements and absence of balance control. Traditional therapies show improvements in postural control, mobility and gait. Currently, the use of video games with low cost devices such as Nintendo® Wii Balance Board® and Kinect increases the rehabilitation process in PD patients against traditional rehabilitation. However, video games are designed for healthy people, and they are not appropriate in balance rehabilitation therapy. In this paper, we describe ABAR system, a custom, motivational and adaptive tool to rehabilitate PD patients, to help them recover from balance disorders and regain postural control. To achieve this goal, we will test patients at the beginning and at the end of the clinical study. Clinical tests include: Anterior Reach Test, the Time "Up and Go", the Stepping Test, the 30-second Sit-to Stand Test and functional reach test.

S Albiol-Pérez, J A Lozano-Quilis, H Gil-Gómez, J A Gil-Gómez, R Llorens, Virtual rehabilitation system for people with Parkinson's disease, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 423–426, Laval, France, 10 – 12 Sept. 2012.

Design of a novel virtual reality-based autism intervention system for facial emotional expressions identification, **E Bekele**, **Z Zheng**, **U Lahiri**, **A Swanson**, **J Davidson**, **Z Warren**, **N Sarkar**, Vanderbilt University, Nashville, TN, USA

A virtual reality (VR)-based system for evaluating facial emotion recognition ability of teenagers with autism spectrum disorders (ASD) is presented. This system is integrated with a non-contact eye tracker that allows investigation of eye gaze and eye physiological indices (e.g., blink rate) of the participants while they seek to identify the emotion displayed by the avatars in the VR environment.

Performance and eye data of 12 participants (6 children with ASD and 6 typically developing children) are presented.

E Bekele, Z Zheng, U Lahiri, A Swanson, J Davidson, Z Warren, N Sarkar, Design of a novel virtual reality-based autism intervention system for facial emotional expressions identification, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 427–430, Laval, France, 10 – 12 Sept. 2012.

Subject anonymisation in video reporting: is animation an option?, **A L Brooks**, Aalborg University, Esbjerg, DENMARK

This short-paper contribution questions the potential of a simple automated video-to-animation rotoscoping technique to provide subject anonymity and confidentiality to conform to ethical regulations whilst maintaining sufficient portraiture data to convey research outcome. This can be especially useful for presenting to young researchers whose limited experiences can restrict their ability to draw association between a treatment and subject profile when solely presented textually and/or verbally. The goal of the paper is to provoke discussions on the subject. It is speculated that given a satisfactory result researchers will more easily be able to illustrate in-session action, responses to treatment, and other outcomes.

A L Brooks, Subject anonymisation in video reporting: is animation an option?, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 431–433, Laval, France, 10 – 12 Sept. 2012.

Markerless motion tracking: MS Kinect and Organic Motion OpenStage, **A L Brooks**, **A Czarowicz**, Aalborg University, Esbjerg, DENMARK/Organic Motion, USA

This contribution focuses on the Associated Technologies aspect of the ICDVRAT event. Two industry leading markerless motion capture systems are examined that offer advancement in the field of rehabilitation. Residing at each end of the cost continuum, technical differences such as 3D versus 360 degree capture, latency, accuracy and other issues are discussed. The plusses and minuses are presented including reflections on the evolution of the MS Kinect to be a stand-alone device for PC with a SDK to offer access for creative programmers to develop systems for disabled users. A conclusion is how the SDK enables half-torso and mirroring calibrations offering new opportunities for wheelchair users.

A L Brooks, A Czarowicz, Markerless motion tracking: MS Kinect and Organic Motion OpenStage, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 435–437, Laval, France, 10 – 12 Sept. 2012.

Perceptual game controllers and fibromyalgia studies, **A L Brooks**, **E Petersson Brooks**, Aalborg University, Esbjerg, DENMARK

This pilot study investigated gesture-based control of video games to promote and motivate self-driven home-based aerobic exercise (AE) training regimes to improve pain threshold associated to fibromyalgia. 10 patients were randomized to 10 sessions each led by a non-medical 'game-savvy' PhD Medialogy student. Control was treatment-as-usual (TAU) patients via the patient's doctor who conducted pre- and post- interviews, tests, and VAS registrations of pain, disturbed sleep, lack of energy, and depression. Included was patient-reported global subjective improvement or otherwise. A Nintendo Wii was used with a sports compilation game 'Sports Resort' with the Wiimote MotionPlus Accessory to increase accuracy of gesture. Facilitator in vivo noted observations and the doctors' research were supplemented by multiple angle (3) video cameras synchronized to the game play for correlation analysis. Outcome measures were at baseline and completion. Short-term results were positive of those patients who completed the study (n = 2). 50% drop out at study commencement suggested a sceptical patient attitude. Further drop outs (n = 3) were due to a car accident (n = 1) and recurrence of pain (n = 2). Both patients who

completed showed significant motion improvements and each purchased a Wii for home training following the study. Follow up interviews and tests are planned to question compliance and long-term outcomes. A follow-on comparative study with 39 patients was conducted with two occupational therapist students replacing the Medialogy student as session facilitator. Three game platforms were studied: the MS Kinect, Sony MOVE, and Nintendo Wii, with 5 game sessions of one hour being played by each patient in regular lab visits (=15 sessions each). This is reported separately with preliminary findings indicating tendencies in line with this short paper. A more detailed report will be included in the publication of the final work as a whole.

A L Brooks, E Petersson Brooks, Perceptual game controllers and fibromyalgia studies, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 439–441, Laval, France, 10 – 12 Sept. 2012.

Advantages of haptic feedback in virtual reality supported balance training: a pilot study, **I Cikajlo**, **A Krpič**, **A Savanović**, **Z Matjačić**, University Rehabilitation Institute, Ljubljana/Smart Com d.o.o., Ljubljana, SLOVENIA

Repetitive and goal based task supported with virtual reality technology have proven successful in balance training of stroke population. However, adding a haptic experience can besides increasing the difficulty level of the task enable postural responses assessment. We demonstrated in a single subject with stroke that haptic feedback can be used not only for interaction with virtual environment, but also for the assessment of postural responses. After the virtual reality and standing frame supported balance training the subject was introduced to the haptic floor. The acceleration of the standing frame/body provided sufficient information to identify the direction of the postural response that could be critical for fall. The outcomes were comparable with neurologically intact population and could be applied for objective postural response evaluation.

I Cikajlo, A Krpič, A Savanović, Z Matjačić, Advantages of haptic feedback in virtual reality supported balance training: a pilot study, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 443–446, Laval, France, 10 – 12 Sept. 2012.

Interactive expressive virtual characters: challenges for conducting experimental studies about multimodal social interaction, **M Courgeon**, **O Grynszpan**, **S Buisine**, **J-C Martin**, LIMSI-CNRS, Orsay/Université Pierre et Marie Curie, Paris/Arts et Métiers Paris Tech, Paris, FRANCE

Advanced studies about social interaction address several challenges of virtual character research. In this paper, we focus on the two following capacities of virtual characters that are the focus of research in human-computer interaction and affective computing research: 1) real-time social interaction, and 2) multimodal expression of social signals. We explain the current challenges with respect to these two capacities and survey how some of them are used in experimental studies with users having Autism Spectrum Disorders (ASD).

M Courgeon, O Grynszpan, S Buisine, J-C Martin, Interactive expressive virtual characters: challenges for conducting experimental studies about multimodal social interaction, *Proc. 9th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 447–449, Laval, France, 10 – 12 Sept. 2012.

Neurocognitive rehabilitation approach for cerebral palsy syndrome by using the rhythm-based tapping tool to extend fields of perception and motion, **M Fukudome**, **H Wagatsuma**, **K Tachibana**, **K Sakamoto**, Kyushu Institute of Technology, Kitakyushu/RIKEN Brain Science Institute, Saitama/Ibaraki Prefectural University of Health Sciences, Inashiki-Gun Ibaraki/Tohoku University, Sendai, JAPAN

We focus on the difficulty of children with cerebral palsy to perform not only motor skills but also cognitive tasks, and hypothesize that rhythm-based tapping tasks help to enhance abilities of motions and cognitions cooperatively, if a personally-tailored rhythm is provided. In the experiment with the prototype tapping device, we found that a misalignment of the pacemaker with the

internally-comfortable tempo brings subjects a feeling of discomfort and declination of performance if the task is in a rushed condition. This result suggests that a self-motivated rhythm may be enhanced through synchrony with the external rhythm, while it is disturbed by a gap between internal and external rhythms. This is an important step towards developing a rhythm-based rehabilitation method and a design principle focusing on subjects' individual internal rhythms.

M Fukudome, H Wagatsuma, K Tachibana, K Sakamoto, Neurocognitive rehabilitation approach for cerebral palsy syndrome by using the rhythm-based tapping tool to extend fields of perception and motion, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 451–454, Laval, France, 10 – 12 Sept. 2012.

Virtual rehabilitation of the weigh bearing asymmetry in the sit-to-stand movement, **J A Gil-Gómez**, **H Gil-Gómez**, **S Albiol-Perez**, **J A Lozano-Quilis**, Universitat Politècnica de València/Universidad de Zaragoza, Teruel, SPAIN

Weight bearing asymmetry is frequently used as a measure of impairment in balance control, and recovering symmetry in weight bearing is considered an imperative objective of rehabilitation. WBA rehabilitation is especially important for the sit-to-stand movement. Transition between sitting and standing, or vice versa, is one of the most mechanically demanding activity undertaken in daily life. In this contribution, we present a Virtual Rehabilitation system specifically designed for the recovery of the symmetry for this movement. The system has been designed with clinical specialists, and it presents very promising features such as the automatic adaptation to the patient. The paper is a work-in-progress that describes the system and presents the validation study that we will follow in a metropolitan hospital. Currently, we are enrolling patients, and the clinical specialists are very encouraged about the potential of the system.

J A Gil-Gómez, H Gil-Gómez, S Albiol-Perez, J A Lozano-Quilis, Virtual rehabilitation of the weigh bearing asymmetry in the sit-to-stand movement, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 455–458, Laval, France, 10 – 12 Sept. 2012.

Reproduction of plosive sound vocalization by the talking robot based on the visual information, **M Kitani**, **H Sawada**, Kagawa University, JAPAN

The authors are developing a vocalization training system for the auditory-impaired. The training system employs a talking robot which has mechanical organs like a human. With an adaptive learning strategy using an auditory feedback control, the robot autonomously learns the vocalization to speak like a human, and then reproduces the speech articulation from inputted vocal sounds. In the previous study, the training system for 5 Japanese vowels was constructed. The effectiveness was assessed by a training experiment conducted in Kagawa Prefectural School for the Deaf, and significant results were obtained. In the next step, the training system for consonant vocalization is studied. The plosive sounds such as /*p*/, /*t*/ and /*k*/ are produced by sudden opening and closing motions of a mouth, and it is not an easy task to reproduce the vocalization based on the auditory feedback learning. To solve this problem, visual information is employed to reproduce the plosive sound vocalization by the talking robot. In this study the learning method of the plosive sounds is introduced. The reproduced robotic vocalizations are evaluated by an experiment, and we validated that the robot successfully reproduced the vocalizations of the able-bodied.

M Kitani, H Sawada, Reproduction of plosive sound vocalization by the talking robot based on the visual information, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 459–462, Laval, France, 10 – 12 Sept. 2012.

Upper limb tracking using depth information for rehabilitative tangible tabletop systems, **R Lloréns**, **C Marín**, **M Ortega**, **M Alcañiz**, **C Colomer**, **M D Navarro**, **E Noé**, Universitat Politècnica de València/Univesity of Jaume I, Castellón/Hospitales NISA Valencia al Mar y Sevilla Aljarafe, Valencia, SPAIN

The motor impairments that affect the upper limb, such as those following an acquired brain injury, are particularly disabling, since this body segment is involved in the majority of the activities of daily living. Virtual reality systems have been reported to stimulate the clinical effectiveness of the rehabilitative strategies, providing intensive and repetitive exercises in a motivating and controllable environment. The tracking of the upper limb movements in the real world is a challenging task that has traditionally involved different tracking systems. The use of depth sensors can provide a non-invasive solution that can be integrated in tabletop systems.

R Lloréns, C Marín, M Ortega, M Alcañiz, C Colomer, M D Navarro, E Noé, Upper limb tracking using depth information for rehabilitative tangible tabletop systems, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 463–466, Laval, France, 10 – 12 Sept. 2012.

Convergent validation of a virtual reality-based street crossing with neuropsychological tests in neglected and non-neglected stroke patients, **R Lloréns**, **M D Navarro**, **M Alcañiz**, **C Colomer**, **E Noé**, Universitat Politècnica de València/Hospitales NISA Valencia al Mar y Sevilla, Aljarafe/Univesity of Jaume I, Castellón, SPAIN

Unilateral spatial neglect is one of the most common and disabling impairments of stroke. The assessment of this deficit is carried out with paper and pencil tasks that can lack correspondence to everyday activities. Virtual reality can recreate realistic but safe environments that allow the therapists to study how the patients would react in real life situations. This paper presents a virtual street-crossing system that immerses the participants in a recreated street where they are asked to navigate safely. The presented study with chronic stroke patients showed remarkable correlations of the performing variables of the system with standard cognitive scales, which suggests that virtual reality systems can evidence alterations in cognitive skills, such as neglect.

R Lloréns, M D Navarro, M Alcañiz, C Colomer, E Noé, Convergent validation of a virtual reality-based street crossing with neuropsychological tests in neglected and non-neglected stroke patients, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 467–470, Laval, France, 10 – 12 Sept. 2012.

Virtual 3D shape and orientation discrimination using point distance information, **S Maidenbaum**, **R Arbel**, **S Abboud**, **D R Chebat**, **S Levy-Tzedek**, **A Amedi**, The Hebrew University of Jerusalem, ISRAEL

Distance information is critical to our understanding of our surrounding environment, especially in virtual reality settings. Unfortunately, as we gage distance mainly visually, the blind are prevented from properly utilizing this parameter to formulate 3D cognitive maps and cognitive imagery of their surroundings. We show qualitatively that with no training it is possible for blind and blindfolded subjects to easily learn a simple transformation between virtual distance and sound, based on the concept of a virtual guide cane (paralleling in a virtual environment the "EyeCane", developed in our lab), enabling the discrimination of virtual 3D orientation and shapes using a standard mouse and audio-system.

S Maidenbaum, R Arbel, S Abboud, D R Chebat, S Levy-Tzedek, A Amedi, Virtual 3D shape and orientation discrimination using point distance information, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 471–474, Laval, France, 10 – 12 Sept. 2012.

Self-referencing virtual reality programs for neurorehabilitation, **L Mendes**, **A I Mota**, **F Barbosa**, **R Vaz**, University of Porto, PORTUGAL

Virtual Reality (VR) is a recent technology to assist in therapy and neurorehabilitation. In doing so, VR enables a realistic performance, with higher motivation and immersion in the problematic situation. VR increases ecological value and skills generalization; however this technology is still disorder-oriented. Patient's response to treatment differs from patient to patient. So it is relevant to take into consideration a multitude of aspects, self-referencing VR Programs for Neurorehabilitation. We argue the need to create a variety of scenarios that better adapt to psychological, developmental and ecological characteristics of each patient.

L Mendes, A I Mota, F Barbosa, R Vaz, Self-referencing virtual reality programs for neurorehabilitation, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 475–478, Laval, France, 10 – 12 Sept. 2012.

Configuring a mobile platform for daily-life management following brain injury: a case study in ubiquity, agility and ethics, **J R O'Brien**, University College London, UK

This paper offers a case study of a participant experiencing neurological impairments after brain injury who uses his mobile platform to author the management of his daily life. The study draws on the participant's own descriptions to propose delineations of the tropes 'ubiquity' and 'agility' with reference to technology participation in daily life. The study attends to an ethical research matter of privacy in the study of daily-life management, not least where the participant has recorded others' personal details. In conclusion, ethical parameters are established for a closer study of technology ubiquity and agility in daily life after brain injury.

J R O'Brien, Configuring a mobile platform for daily-life management following brain injury: a case study in ubiquity, agility and ethics, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 479–482, Laval, France, 10 – 12 Sept. 2012.

Development of a system for the assessment of a dual-task performance based on a motion-capture device, **K Okamoto**, **H Kayama**, **M Yamada**, **N Kume**, **T Kuroda**, **T Aoyama**, Kyoto University Hospital/Kyoto University, JAPAN

The authors produced a dual-task (DT) which provides a dynamic balance task and a cognitive task in a game system using motion sensors and virtual images. There had been no DT where a cognitive task needs a dynamic balance task which requires full body motions. We developed and evaluated a game system to assess the performance of the DT. The DT is to solve Sudoku using full body motions like Tái Chi. An ability to perform a DT is intimately related to risk of falls. To evaluate the developed system, we compared the performance of elderly people and young people. Generally, elderly people are at a higher risk of falls. 20 elderly community-dwelling adults (mean age, 73.0 ± 6.2 yrs.) and 16 young adults (mean age, 21.8 ± 1.0 yrs.) participated in this study. To compare the two groups, we applied an independent-samples *t*-test. The time taken for the elderly people was 60.6 ± 43.2 seconds while the time taken for the young people was 16.0 ± 4.8 seconds. The difference is statistically significant ($p < 0.05$). This result suggests that the developed game system is useful for the evaluation of the DT performance.

K Okamoto, H Kayama, M Yamada, N Kume, T Kuroda, T Aoyama, Development of a system for the assessment of a dual-task performance based on a motion-capture device, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 483–486, Laval, France, 10 – 12 Sept. 2012.

Counting repetitions of upper extremity movements while playing video games compared to traditional therapy; implications for stroke rehabilitation, **D Rand**, **N Givon**, **G Zeilig**, **A Nota**, **H Weingarden**, Tel Aviv University/ The Chaim Sheba Medical Center, Tel-HaShomer, ISRAEL

Clinicians are seeking novel methods to increase the number of repetitions of purposeful movements during and following stroke rehabilitation. Video-game consoles encourage active purposeful movement, however, the number of repetitions while playing video games is unknown. We aimed to compare the number of repetitions and accelerometers activity counts of movements of the weak upper extremity of individuals with chronic stroke while playing video games to participants in traditional therapy. Eight participants were included. Differences between groups in the type and number of repetitions and accelerometers activity counts were found. These preliminary findings indicate that video-games facilitate multiple repetitions of fast purposeful movements.

D Rand, N Givon, G Zeilig, A Nota, H Weingarden, Counting repetitions of upper extremity movements while playing video games compared to traditional therapy; implications for stroke rehabilitation, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 487–490, Laval, France, 10 – 12 Sept. 2012.

Promoting ability with interactive artistic environments, **K Sá**, **A M Almeida**, **A Moreira**, University of Aveiro, PORTUGAL

The intention of this project derives from the beauty of the field of arts and from interaction and immersion paradigms, which are today potentiated by multisensory and multimodal feedback in technological environments. We wanted to see the impact of interactive artistic environments on students with special needs, as a form of self-expression and inclusion, in a real school context. Emphasizing the actual Portuguese inclusive school framework, this study was carried out in a public education establishment, with twelve students from individualized special curricula. *Special INPUT* was the concept of different types of environments and interaction approaches were implemented in individual sessions with the participants, which allowed to promote and observe their intellectual, emotional, personal, interpersonal, intrapersonal, psychomotor and artistic skills. At the moment, we have not yet closed the study, so our presentation focuses on the process, as there are no final results.

K Sá, A M Almeida, A Moreira, Promoting ability with interactive artistic environments, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 491–494, Laval, France, 10 – 12 Sept. 2012.

Generative design as a method to foster explorative behaviour in virtual motor rehabilitation, **T Schüler**, University of Osnabrück, GERMANY

The article contrasts the bottom-up with the top-down approach to the development of systems for virtual motor rehabilitation. A research project is presented that uses the top-down approach for the development of a system for virtual neurorehabilitation of amputees suffering from phantom limb pain. Artistic visualisations that are inspired by the field of generative design will be used to constitute the illusion of a moving phantom limb. The coupling between the movements of the patients and the visual effect is not straightforward but needs to be discovered through explorative behaviour. It is assumed that this will help the patients to concentrate on the treatment and therefore a strong therapeutic effect will be achieved.

T Schüler, Generative design as a method to foster explorative behaviour in virtual motor rehabilitation, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 495–498, Laval, France, 10 – 12 Sept. 2012.

Virtual office for students with learning difficulties, **C Sík Lányi**, **G Sádori Pap**, University of Pannonia, Veszprém, HUNGARY

People with learning difficulties often face lack of opportunities in their everyday lives, and less than 10% of them have a job (Brown et al, 2010). This group needs additional support and innovative pedagogical approaches, matched to their needs, to develop skills for work and independent living. We developed a virtual office for students with learning difficulties, which teaches them how to get their first identity or national health insurance card, passport and European health insurance card. In this paper we address questions related to the design and evaluation of games developed to suit the needs of people with individual learning needs.

C Sík Lányi, G Sádori Pap, Virtual office for students with learning difficulties, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 499–502, Laval, France, 10 – 12 Sept. 2012.

Developing serious games for victims of stroke, **C Sík Lányi**, **V Szűcs**, **E László**, **T Dömők**, University of Pannonia, Veszprém, HUNGARY

This study introduces Serious games, which are special games planned within the "StrokeBack" project. The aim of these games is to support the rehabilitation process of stroke patients who have upper limb impairments and damaged psychomotor abilities. In this paper we will present the methodology and ideology of Serious games, and we will prove the importance and necessity of developing such tool.

C Sík Lányi, V Szűcs, E László, T Dömők, Developing serious games for victims of stroke, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 503–506, Laval, France, 10 – 12 Sept. 2012.

Virtual reality and brain-computer interface for joint-attention training in autism, **M Simões**, **P Carvalho**, **M Castelo-Branco**, University of Coimbra, PORTUGAL

Autism Spectrum Disorders (ASD) are characterized by three core behaviours: deficits in social interactions, in communication and repetitive and restricted behaviours. One of the pivotal skills we acquire for social interaction is joint attention, which has been also related to communication skills. The systemizing theory of Autism suggests that these individuals have a preference for computerized systems because of its structure and deterministic functioning. It is hypothesized that Virtual Reality may play an important role for teaching social skills in these individuals, since it can mimic the real world in a more controlled way. In this paper, we propose the use of VR for the training of joint-attention skills in Autism using a Brain-Computer Interface. We developed environments where a virtual human character directs attention to a virtual object in the environment, which the user is supposed to identify by paying attention to it. The subject's brain activity is monitored in real time by electroencephalogram (EEG) and a classifier tries to identify the target object detecting the P300 wave in the EEG. Preliminary results show a classification accuracy of 90% encouraging the approach.

M Simões, P Carvalho, M Castelo-Branco, Virtual reality and brain-computer interface for joint-attention training in autism, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 507–510, Laval, France, 10 – 12 Sept. 2012.

Robotic rehabilitation tool supporting up and down motions in the bathroom – analyses of the catapult-assisted taking-off mechanism, **M Sone**, **H Wagatsuma**, **K Tachibana**, **K Sakamoto**, Kyushu Institute of Technology, Kitakyushu/RIKEN Brain Science Institute, Saitama/Ibaraki Prefectural University of Health Sciences, Inashiki-Gun Ibaraki/Tohoku University, Sendai, JAPAN

Flexibility and quickness of biological muscles are of interest to people developing welfare robots and studying physiotherapy procedures. We focus on the transition process from sitting to standing in human motions, which needs to generate an instantaneous force at the moment of standing, and propose a robotic device to help the up-and-down motion in the bathroom by assisting the force when the backside is taking off from the lavatory basin. Our lightweight construction device allows disabled persons to move easily from the living space to the bathroom and assist its motion from the viewpoint of rehabilitation. In the prototype experiment, the artificial muscle—based on elastic-plastic materials by using rebound characteristics in an S-shaped structure—demonstrated that a cyclic motion triggers a generation of instantaneous force large enough to launch a ball. This suggests that the combination of the movable frame with the human body and the artificial muscle mechanism provide a user-friendly tool for self-supporting life of disabled persons.

M Sone, H Wagatsuma, K Tachibana, K Sakamoto, Robotic rehabilitation tool supporting up and down motions in the bathroom – analyses of the catapult-assisted taking-off mechanism, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 511–514, Laval, France, 10 – 12 Sept. 2012.

Personalised stroke rehabilitation intervention using open source 3D software and the Wii Remote Plus, **E Tsekleves**, **D Skordoulis**, **I Paraskevopoulos**, **C Kilbride**, **A Warland**, Brunel University, Uxbridge, UK

The research presented in this paper proposes a novel low-cost customised Virtual Reality (VR) based, stroke rehabilitation system for the delivery of motivating rehabilitation sessions and evaluation of performance. The described system is designed to capture and monitor human upper limb motion using a low cost and commercially available accelerometer and gyroscope device, the Nintendo Wii remote and open source 3D software. This is the first project to successfully fuse the Nintendo Wii remote acceleration and gyroscope data to offer a real-time one-to-one representation of the controller in a VR environment. A pilot study established a high degree of user acceptability and high levels enjoyment using the tailor made games and personalised exercises in a chronic stroke survivor. Moreover, positive changes were demonstrated in all four outcome measures employed; of particular note were improved wrist control and greater functional use of the hand.

E Tsekleves, D Skordoulis, I Paraskevopoulos, C Kilbride, A Warland, Personalised stroke rehabilitation intervention using open source 3D software and the Wii Remote Plus, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 515–518, Laval, France, 10 – 12 Sept. 2012.

Relationship between sensory processing profiles and sense of presence, **H S Wallach**, **M P Safir**, **R Horef**, University of Haifa, ISRAEL

'*Sensory Processing*' is the distinction, modulation and response to sensory input, and combines high or low neurological thresholds and high or low behavioral responses. We examined the impact of sensory processing on sense of presence in a flight VRE. Subjects (85) completed the Adult Sensory Profile, experienced a 10 minute VRE and completed presence questionnaires. According to expectations, Sensory Sensitivity correlated positively with presence for Minority (Arab) participants and those who failed to look at the window, and Sensory Avoidance correlated positively with presence. Contrary to expectations Sensory Sensitivity correlated negatively with presence for Majority (Jewish) participants and Sensory Avoidance correlated negatively with presence for Minority (Arab) participants. We conclude that for high Sensory Sensitivity individuals it is essential to ensure that distracting technological and environmental stimuli are kept to a minimum; for High Sensory Avoidant individuals, control of the environment is important; for those high on Sensory Seeking, interactivity in the VRE is important to enhance presence.

H S Wallach, M P Safir, R Horef, Relationship between sensory processing profiles and sense of presence, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 519–522, Laval, France, 10 – 12 Sept. 2012.

Haptics visualisation of scientific data for visually impaired users, **R J White**, **W S Harwin**, University of Reading, UK

Visualisations of numerical data often used in science, engineering and mathematics are not easily accessible to visually impaired students. This paper describes the development and evaluation of a multimodal system to present graphical data in real-time to those students. Haptic interfaces form the primary interaction, along with auditory feedback allowing graphs to be perceived through touch, sounds and speech. The results show that the system can be used to quickly and accurately obtain information from a graph. It has been demonstrated that haptic devices can be successfully used to allow access to line graph data.

R J White, W S Harwin, Haptics visualisation of scientific data for visually impaired users, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 523–526, Laval, France, 10 – 12 Sept. 2012.

Augmented reality discovery and information system for people with memory loss, **S Wood**, **R J McCrindle**, University of Reading, UK

Augmented Reality (AR) merges computer generated objects with real world concepts in order to provide additional information to enhance a person's perception of the real world. This paper describes the work undertaken for an MEng project to investigate the potential of using AR to assist people who have memory loss with simple everyday tasks such as making a hot drink or cooking basic meals. The aim of the Augmented Reality Discovery and Information System (TARDIS) is to help people live independently in their own homes for as long as possible and without relying as heavily on carer support.

S Wood, R J McCrindle, Augmented reality discovery and information system for people with memory loss, *Proc. 9th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, P M Sharkey, E Klinger (Eds), pp. 527–530, Laval, France, 10 – 12 Sept. 2012.

Virtual reality for cognitive rehabilitation: from new use of computers to better knowledge of brain black box?

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ABSTRACT

Virtual reality based technologies are one of the emerging tools that appear to have great potential for use in cognitive rehabilitation but it still is unclear how brain capacities are involved and what is the best approach to such training. At first, virtual reality was mainly used in single user virtual environments, but social interaction should also be addressed using collaborative virtual environments (CVE). In a CVE, multiple users can interact and collaborate with each other, solve complex tasks and learn with each other. Regarding to impact of behavioral disturbances in family stress and social re-entry, such tools need to have a wider use in future years.

Quantitative aspects are encouraging as some improvement have been shown after few training sessions. Home retraining or telerehabilitation based on VR may bridge the gap between lack of specialized resources and growing number of patients. Qualitative design of VR tools is more questionable. Choice of errorless or errorfull designs may depend on the severity of disturbances. Most VR tools emphasize the explicit component of tasks, even procedural aspects are a main strength of VR retraining programs. VR and augmented reality tools give various stimuli and indicators but their best modalities stay unclear, as most data are coming from learning studies in normal subjects more than rehabilitation studies in brain injured patients. Specific research studies to explore impact of sensorial transmodal effects and emotional involvement in VR tasks are requested. Rehabilitation protocols utilizing virtual environments are moving from single applications to cognitive impairment (i.e. alert, memory, neglect, language, executive functions) to comprehensive rehabilitation programs with the aim of efficient improvement in autonomy and transfer of benefits in real life conditions. A core issue that presents challenges to rehabilitation is decreased ability of persons with brain injury to transfer learning from one situation or context to another. The multicontext approach to cognitive rehabilitation proposes treatment methods for teaching use of strategies across a wide range of meaningful activities to promote generalization and enhance functional performance.

VR offers a very promising and exciting support for cognitive rehabilitation but we have to move from mimicking “in room” or desk rehabilitation practice to specific VR programs to maximize benefits and to get optimal improvement in cognitive and behavioral autonomy of patients.

1. INTRODUCTION

At first, virtual reality (VR) based tools were developed from an educational perspective. Then VR systems had targeted a wide range of physical, cognitive, psychological rehabilitation concerns. Virtual environments can be developed to present simulations that assess and rehabilitate cognitive functional performance under a range of conditions that are not easily deliverable and controllable in the real world. By providing a safe setting in which users may interact and develop goal-oriented activities within a virtual environment, VR allows the delivery of controlled multisensory stimuli and the creation of innovative learning and training approaches. VR offers the potential to create systematic human testing, training, and treatment environments that allow for the precise control of complex, immersive, dynamic stimulus presentations, within which sophisticated interaction, behavioural tracking, and performance recording is possible (Rizzo & Kim 2005).

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The use of virtual-reality technologies in the areas of rehabilitation and therapy continues to grow, with encouraging results being reported for applications that address human physical, cognitive, and psychological functioning. However, there is currently little information from clinical trials about their effectiveness (Laver et al. 2011). The studies involved small numbers of participants and intervention approaches in the studies were predominantly designed to improve motor function rather than cognitive function or activity performance (Klinger et al. 2010).

2. STRENGTH AND WEAKNESSES OF VR TECHNOLOGIES REGARDING COGNITIVE REHABILITATION

Immersion and interaction are two fundamental functionalities of VR that can be exploited at different levels: sensorimotor, cognitive and functional (Fuchs et al. 2006; Klinger 2006). VR situations substantially change the information-processing capacities of the cognitive system and that warrants investigation and understanding. VR is used for cognitive learning by way of repetition, feedback which can be augmented in VR, errorless training with explicit or implicit cues.

2.1 A Way to Improve Self Awareness in Cognitive Deficits

Anosognosia and less dramatic disturbances in self-awareness observed in various brain disorders are weakly addressed by conventional rehabilitation (Prigatano 2009). VR may support patients' improvement of self awareness and better understanding of mistakes and inadequate strategies, by way of easier assisted sequential tasks (e.g. step by step or cues during process) or replay after exercise. Motivation in virtual environments is reinforced by making sense and a feeling of success, allowing the high number of repetitions necessary to achieve learning.

2.2 From Hospital Acute Phase to Home-based Rehabilitation even in Severely Handicapped

Even subjects with severe motor or sensorial deficits, who cannot cope with many of the difficulties of conventional rehabilitation session, may practice exercises in VR environment. It enables patient to practice skill in ways he cannot achieve in the physical world. A wide range of virtual reality programs are used and most of the programs require only small movements by the person using the program, such as moving a joystick or as utilizing a keyboard, in a sitting position. Even patients who are not familiar with computers can perform rehabilitative exercises.

2.3 Low Incidence of Side Effects

Very few people using virtual reality in brain injury patients reported pain, headaches, epileptic seizures or dizziness and no serious adverse events were reported. These side effects mainly occur with Head Mounted Displays (HMD) and large screen driving simulators, and are much less relevant for desktop or video capture systems that are mainly used in VR-based rehabilitation.

2.4 A Holistic Rehabilitation which makes sense for Real Life and Activities of Daily Living

The tremendous advances in technologies over the past two decades have focused primarily on the realism of the virtual environment tools, and the complexity and performance of simulations and data collection. However, real time interactivity of the device is the key point for immersion more than realism. Cognitive rehabilitation programs are focused on single process such as memory, attention, executive functions, visuo-spatial abilities, neglect, etc… These approaches have shown some efficacy regarding trained domains but effects in real life conditions are still poor and lack the ability to develop efficient autonomy. Understanding performance and training in VR conditions involve not only a single cognitive process or network but the whole activity system which comprises a group of human actors, their tools and environment, in a distributed cognitive perspective, and is organized by a particular history of goal-directed action and interaction. Brain damaged patients may exploit "intelligence" from objects when they use them instrumentally in VR activities, that is to say bottom-up abilities and implicit holistic know-how.

Consequences in daily life of cognitive deficits are still difficult to identify and VR testing is promising in that way. VR systems appear to be perceived to be closer to real activities than conventional exercises, by the way of delivery and control of ecological and appropriate multimodal stimuli within a significant and familiar context (e.g., classroom, office, supermarket or street). Patients have to cope with more dynamic stimuli, as is the case for real world challenges. VR allows patients to practice everyday activities that are not or cannot be practiced within the hospital or day living center environment. Home retraining or telerehabilitation based on VR may bridge the gap between a lack of specialized resources and a growing

number of patients. In cognitive brain impaired people, VR makes activities feasible for more patients, allowing them to respond to and perform tasks in less complex ways that entail a simplified cognitive load with minor simultaneous motor control requirements. The multicontext approach to cognitive rehabilitation proposes treatment methods for teaching use of strategies across a wide range of meaningful activities to promote generalization and enhance functional performance (Abreu & Toglia1987).

2.5 A New Way to Cope with Emotional and Behavioural Disturbances

Emotions play a key role in the user experience, in the development of more engaging rehabilitation programs, and increasing attention and learning. A significant effort has to be made in the modeling of emotions, their generation and their effects in VR cognitive rehabilitation. Many advances have been made in machine recognition of emotions over the past 10 years (Hudlicka 2009). This progress allows the implementation of affective game engine functionalities to support the development of affect-adaptative rehabilitation programs. Once diagnosed, treatment of depression and other emotional disorders can greatly improve rehabilitation outcomes (Kimura 2000, Wiart 2000).

2.6 What are we doing? More Concerns about Procedural Processes and Bottom-up Learning

Most VR tools emphasize the explicit component of tasks, even procedural aspects are a main strength of VR retraining programs. VR and augmented reality tools give various stimuli and indicators but their best modalities stay unclear, as most data are coming from educational in normal subjects more than rehabilitation studies in brain injured patients.

Observation of patient behavior thanks to various recorded data for performance review and construction of adapted interventions – the tasks in which the patient is involved – allow clinicians to collect detailed information about the process of patient performance rather than focusing primarily on a final product (e.g., the juxtaposition of types of errors to task requirements versus only an overall total error score). An analysis of these “learning tracks” leads to suggestions for further intervention adapted to the patient’s capacities or to the therapeutic challenge. Construction of new intervention paradigms – VR allows clinicians to manipulate a variety of features, such as space, 3D entities, time, physical laws, information (via texts, icons or sounds), – leads to the provision of standardized and repeatable experiments, or personalized and gradable ones.

3. WHAT DO WE LEARN FROM CONVENTIONAL REHABILITATION AND COGNITIVE REORGANIZATION ?

Cognitive deficits after brain diseases are very common. Although there are anecdotal and large case studies supporting the benefits of cognitive remediation, evidence-based research is lacking and most research has been in the traumatic brain injury population. The data supports a thorough assessment of cognitive functioning as well as treatment of patients with several areas of cognitive impairment via multiple disciplines (Bates 2005). There is substantial evidence to support cognitive-linguistic therapies for people with language deficits after left hemisphere stroke. Specific interventions for functional communication deficits, including pragmatic conversational skills are recommended for persons with TBI. Some evidence supports training for apraxia after stroke. The evidence supports visuospatial rehabilitation for deficits associated with visual neglect after right hemisphere stroke. There is substantial evidence to support cognitive rehabilitation for traumatic brain injured patients, including compensatory strategy training for mild memory impairment, strategy training for post acute attention deficits, and interventions for functional communication deficits (Cicerone et al. 2000, 2005). Use of memory notebooks or other external aids to facilitate acquisition of specific skills and knowledge may be considered for persons with moderate to severe memory impairments after traumatic brain injury; these devices should directly apply to functional activities, rather than as an attempt to improve memory function per se. Training in formal problem-solving strategies and their application to everyday situations and functional activities are recommended during post acute rehabilitation for persons with stroke or traumatic brain injury. Comprehensive-holistic neuropsychological rehabilitation is recommended to reduce cognitive, behavioral and functional disability after TBI. Memory stimulation programs used in the treatment of Alzheimer’s disease (AD) are using visual imagery, errorless learning, dyadic approaches, spaced retrieval techniques, encoding specificity with cognitive support at retrieval, and external memory aids were the memory stimulation programs used alone or in combination in patients with AD. Preliminary evidence suggests that the errorless learning, spaced retrieval, and vanishing cues techniques and the dyadic approach, used alone or in combination, are efficacious in stimulating memory in patients with AD (Grandmaison, 2003).

Cognitive rehabilitation typically relies on individually tailored interventions to provide the best available treatment within a clinical setting. For many, the real work of recovery begins after formal rehabilitation

when the patient attempts to use newly learned skills without the support of the rehabilitation environment or team. Adequate support from family and caregivers is critical to a successful outcome. A holistic approach that has, as its basic philosophy, a belief that cognitive functions cannot be divorced from emotion, motivation, or other non cognitive functions, and consequently all aspects of functioning should be addressed in rehabilitation programs (Wilson 1997). Long term follow-up and late rehabilitation can improve performance in some cases and reduce the risk of deterioration in these abilities in many people (Outpatients Service Trialists 2004, Cicerone et al. 2005).

3.1 Quantitative Aspects in Cognitive Rehabilitation

Therapy is most effective in treating cognitive disorders when provided intensely; less intensive therapy given over a longer period of time does not provide a statistically significant benefit, although some clinical benefit may be achieved (Wilson 1997, Robbey 1998, Cicerone et al. 2005). The recent Cochrane update (Kelly et al. 2010) in stroke aphasics rehabilitation reported that intensive therapy was associated with improved outcome when compared to conventional treatment; however, more participants withdrew from intensive therapy conditions than conventional. By progressive training and greater repetition VR is an efficient way to give more training and to complete adequate care from the beginning of illness, during hospitalization, to the long term in home environment.

A promising result regarding VR applications to cognitive deficits is that short treatment programs of 3 or 4-week interventions with three sessions per week have shown some effectiveness (Klinger et al. 2010). Training post effects were observed and follow-up assessments argue for transfer of gain in VR environment to real life settings. Present data are encouraging, especially regarding spatial learning, but have to be confirmed in larger controlled studies. VR applications permit some containment of costs, in terms of staff time, and risks to both patients and staff, which are incurred when training in real world situations.

3.2 Qualitative Aspects in Cognitive Rehabilitation

Cognitive rehabilitation is usually presented from an information processing perspective (Abreu & Toglia 1984). Cognitive trainings involves:

- processing of information: ability to receive, elaborate, and monitor incoming information;
- generalization of learning: flexibility to use and apply one's analysis of information across task boundaries;
- the use of metacognitive skills (higher level skills or executive functions) including self awareness, goal formation, planning, and monitoring during task performance.

Several cognitive remediation or stimulation programs have been developed to compensate for the impairments associated with some necessary skills involved in the process of learning, such as the encoding and retrieval capacities. These capacities are typically altered in classical amnesic syndromes and in cases of brain damage, causing severe memory problems and other cognitive deficits. The theoretical goal of the strategies reported in the literature is to improve or support damaged functions in order to facilitate new learning. These different strategies have not yet been used to strengthen or improve areas not damaged, but they can partially rely on these undamaged areas (such as implicit memory) to carry on the training and improve learning capacity. Visual imagery techniques or encoding specificity strategies with cognitive support in episodic remembering necessitate sufficient residual cognitive abilities; the errorless learning approach and vanishing cues techniques have been developed for more impaired subjects. The training programs can be used individually or in combination. Choice of errorless or errorfull designs may depend of severity of disturbances. Specific skill training follows a hierarchy : orientation and arousal, attention, visual processing and language, motor planning and sequencing, memory, categorization and concept formation, and problem solving in task performance.

Errorless learning, a procedure introduced by Terrace (1963), is a type of discrimination learning that decreases or eliminates the opportunity for incorrect choice selection, therefore maximizing the possibility of a correct response. Errorless learning allows learning to occur with few or no negative stimuli. Errorless learning has been contrasted with trial and error learning in which the learner attempts a task and then benefits from feedback, whether the attempt was correct or incorrect. Trial and error learning may have the added advantage of producing deeper understanding – but only for those individuals who remember the learning experience (Sharp et al. 2011). The finding that patients with amnesia retain the ability to learn certain procedural skills has provided compelling evidence of multiple memory systems in the human brain, but the scope, defining features and ecological significance of the preserved mnemonic abilities have not yet been explored. Subjects with amnesia would be able to learn and retain a broad range of procedural skills.

Errorless learning minimizes the number of errors, increases overall time available for instruction, reduces the likelihood that errors will be repeated in future trials and should also reduce frustration and the occurrence of inappropriate emotional behaviors by increasing opportunities for reinforcement. Learning on the basis of predictable stimulus-outcome associations enables the brain to reduce resources in association with the processes of prediction (K Koch et al. 2008) so errorless learning appears to be more efficient than reward-related learning in severe cognitive deficit. Errorless learning strategies have been applied to a variety of fields with success, including learning, memory, aphasia and apraxia.

Usually, cues are gradually introduced. By way of giving assistance as sparsely as possible, the therapist encourages an effortful approach which enhances patient's chance to perform it later on. But the high opportunity to make errors may be disadvantageous. As an alternative, the method of *vanishing cues* (Glisky, Schacter & Tulving 1986, Abel et al. 2005), which was initially designed for treatment of memory disorders, provides as much assistance as needed, thereby helping patients to avoid errors. The vanishing cues technique consists of several attempts to recall information, using prompts that are gradually decreased until recall is successfully achieved. Cue hierarchy progresses from most potent to least potent until failure, then increases again. This method is mainly based on two well-established and related principles: the backward chaining procedure of behavioral modification and some preservation of implicit memory in subjects with amnesia. Some authors view the vanishing cues technique as a complementary method to achieve an errorless learning training.

Strategies have been developed to provide *supportive conditions at both encoding and retrieval phases of episodic learning*. The encoding specificity paradigm necessitates the use of similar cues for acquisition (or encoding) and retrieval, since this paradigm holds that the amount of informational overlap between a cue presented at retrieval and the memory representation established at encoding is critical to episodic memory proficiency (Tulving &Thomson 1973, Diesfeldt 1984, Nieuwenhuis et al. 2005). In other words, the more congruent a cue is with the context prevailing during encoding or with the cognitive operations associated with encoding, the more effective it will be at retrieval. Being able to learn from feedback or reward and to adapt behavior accordingly is an important capability in everyday life. There is increasing evidence that the mesolimbic dopamine system (MDS) is critically involved in the processing of reward and reward-related learning (McClure et al. 2003). Activation in orbital/medial frontal and MDS regions has been found to be inversely related to the likelihood to receive positive feedback or reward. Therefore, activation in these regions is assumed to constitute the neural correlate of the so-called prediction error that describes the difference between the expected and the received outcome or reward (K Koch et al. 2008). Learning with and without reinforcement has been found to go along with practice-associated cortical activation decreases. These decreases are assumed to reflect a learning-related increase in automated processing, demanding fewer processing resources. Nevertheless such remediation is cognitive resource intensive and so relevant only in slightly impaired patients. Strategies aiming to maximize cues in virtual environments may fail when used in more damaged subjects.

To process information in the environment to meet our survival and personal needs, we need to process *sensory information*. This begins with a relay of visual, auditory, tactile and olfactory information from the sense organs (eye, ear, skin, nose) to primary sensory cells in the cortex (A1, V1 and S1 and the olfactory lobe respectively). Thereafter, sensory information is processed by more complex unimodal associations and ultimately, transmodal projections to other modality associations, allow integration of stimuli into multimodal concepts, like words which can be processed auditorily and visually. Sensory information undergoes extensive associative elaboration and attentional modulation as it becomes incorporated into the texture of cognition. All cognitive processes arise from analogous associative transformations of similar sets of sensory inputs. The human brain contains at least five anatomically distinct networks. The network for spatial awareness is based on transmodal epicentres in the posterior parietal cortex and the frontal eye fields; the language network on epicentres in Wernicke's and Broca's areas; the explicit memory/emotion network on epicentres in the hippocampal-entorhinal complex and the amygdala; the face-object recognition network on epicentres in the midtemporal and temporopolar cortices; and the working memory-executive function network on epicentres in the lateral prefrontal cortex and perhaps the posterior parietal cortex. Individual sensory modalities give rise to streams of processing directed to transmodal nodes belonging to each of these networks (Messulam, 1998, Riddoch & Humphrey 2001).

Usually only a few sensory modalities are provided in virtual environments (most commonly visual and auditory); recent efforts aim to integrate other modalities including haptics, smell and proprioception. But contradictory multisensorial stimuli may lead to conflicts which, in turn, often lead to cybersickness side effects. No study has demonstrated greater effectiveness of the multisensorial system for cognitive rehabilitation and in fact, it may be deleterious. Sensorial inputs in VR cannot be regarding as additive or only associated with brain speed of processing; they are highly integrative and context dependent. Two

mechanisms of bottom-up processing versus top-down processing are involved in sensory processing. Perception must be largely data-driven because it must accurately reflect events in the outside world. In many situations, however, our knowledge or expectations will influence perception. This is called schema-driven or top-down processing. 'Top-down' processes describe knowledge-driven mechanisms. Bottom up perspectives attempt to explain a subject's ability to detect targets and target-triggered attentional processing largely by the sensory salience of the targets, and their ability to trigger attentional processing by recruiting 'higher' cortical areas in a bottom-up manner (e.g., from overlaps and differences the processing of a visual target in the primary visual cortex to temporal regions for object identification and to parietal regions for location). Importantly, 'top-down' and 'bottom-up' processes represent overlapping organizational principles rather than dichotomous constructs, and in most situations, top-down and bottom-up processes interact to optimize attentional performance (Egeth & Yantis 1997, Sarter et al. 2001).Top down processing – processing based on previous knowledge or schemata – allows us to make inferences: to "perceive" or "know" more than is contained in the data. The bottom-up approach of visuo-motor adaptation appears to interact with higher order brain functions related to multisensory integration and can have beneficial effects on sensory processing in different modalities. These findings should stimulate the development of therapeutic approaches aimed at bypassing the affected sensory processing modality by adapting other sensory modalities (Jacquin-Courtois et al. 2010).

Training should include *specific strategies designed to help clients compensate for attention deficits* and improve performance. Examples of strategies include:

- verbal mediation: whereby patients talk themselves through tasks (e.g., verbalize the stimulus dimension to which they are responding on an alternating attention task);
- rehearsal of specific strategies: such as repeating what they are looking for (e.g., descending number sequences on a sustained attention task);
- self-pacing: to reduce the impact of information overload caused by decreased processing speed, teach people to slow down on tasks and to pause between tasks.

The use of positive self-statements intends to reduce frustration and fatigue (Sohlberg &. Mateer 1987, Brain Injury Interdisciplinary Special Interest Group 2002).

Even if permanent damage is present, the individual can be taught to capitalize on existing potentials and strengths and to use strategies to substitute or compensate for limitations. Performance can be enhanced if the environment or the task is modified to accommodate limitations, which can be allowed by VR environments.

4. CONCLUSIONS

Cognitive rehabilitation is a system of therapeutic activities, based on brain-behavior relationships, directed to achieve functional change by re-establishing or reinforcing previously learned patterns of behavior, establishing new patterns of cognitive activity through compensatory cognitive mechanisms, establishing new patterns of activity through external compensatory mechanisms, enabling persons to adapt to their cognitive disability to improve overall functioning.

Virtual reality has the potential to assist current rehabilitation techniques by offering new opportunities for learning and transfer in brain damage rehabilitation. The main focus of much of the exploratory research performed to date has been to investigate the use of VR in the assessment of cognitive abilities, but there is now a trend for more studies to encompass rehabilitation training strategies. There is considerable potential for using VR in cognitive learning rehabilitation which is only just beginning to be realized. PC-based virtual environments are currently preferred for this purpose, rather than the more immersive virtual environments, because they are relatively inexpensive and portable, and easy to use for patients.

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Movement rehabilitation in virtual reality from then to now: how are we doing?

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ABSTRACT

During the past decade there has been a continuous exploration of how virtual environments can be used to facilitate motor recovery and relearning after neurological impairment. The goals for using virtual environments have been to either improve patients' rehabilitation outcomes beyond our current capabilities, or to supplement labor intensive and time consuming therapies with technology based interventions. After over a decade of investigation it seems appropriate to determine whether we are succeeding in meeting our goals.

1. INTRODUCTION

Evolving ideas in neuroscience, computer science and biomedical engineering have greatly influenced the development of a new generation of interventions for physical rehabilitation. During the past decade there has been a continuous exploration of how virtual environments can be used to facilitate motor recovery and relearning after neurological impairment. The literature clearly shows a progression of articles, initially describing the potential applications of this technology, to feasibility studies testing out newly developed systems, to small clinical trials. The construction of virtual environments used to rehabilitate motor deficits has progressed from simple two-dimensional self-timed reaching activities to more complex, immersive three-dimensional externally paced gaming activities that incorporate important tactile information and interaction forces into what had been an essentially visual and auditory experience. Combining adaptive robotic systems that interface with virtual environments has broadened the group of people that can utilize VR and gaming technology for motor rehabilitation. The breadth of the virtual reality (VR) systems ranges from expensive customized systems to less costly commercially available devices. The basis for the use of virtual environments in motor rehabilitation evolved from the concepts of adaptive activity-based neuroplasticity, task-oriented motor training and the need for high doses of repetitive practice. The goals have been to either improve patients' rehabilitation outcomes beyond our current capabilities, or to supplement labor intensive and time consuming therapies with technology based interventions.

After over a decade of investigation it seems appropriate to ask "How We Are Doing?" In two recently published reviews (Laver, George, Thomas, Deutsch, & Crotty, 2011; Saposnik & Levin), the authors found that the use of virtual reality (including interactive gaming) showed slightly better outcomes when compared to conventional therapy for people post stroke. However, there is limited evidence regarding the translation of these selected outcomes to real-world activities of daily living and function. Importantly, the studies \included in these reviews used comparison groups that received alternate interventions or no interventions, but they did not necessarily receive interventions with comparable training intensity. This compromises the interpretation of the benefits of training in VR and leaves us to continue to wonder "How Are We Doing?"

It is therefore time to parse out what we have learned during this past decade of ongoing examination of using virtual environments for motor rehabilitation. This talk will examine a number of important questions including: 1) have virtual reality/robotic interventions provided value in terms of intensity and dosing, 2) do the quantitative/qualitative outcome measures that we have been using allow us to evaluate our subject's progress meaningfully, 3) do we know whether these interventions have been of personal value to the

subjects, 4) can these systems be implemented within the patient-client management models that are currently used in physical rehabilitation, 5) are we utilizing the potential sensory and perceptual aspects of virtual reality in the most beneficial way, and 6) finally, do we have an understanding of the underlying changes in brain connectivity and function elicited by VR interventions? Finding answers to these questions will provide a critical substrate for all future work.

2. VIRTUAL REALITY AS A TOOL TO PROVIDE INTENSIVE INTERVENTION DOSING

Current emphasis in the rehabilitation of neuromotor deficits has been on repetitive task oriented training and progressive practice. It is believed that this motor learning principle parallels the principle of "use-dependent" repeated practice that has been purported to affect neuroplasticity and to modify neural organization. One of the difficulties in designing rehabilitation programs congruent with the literature supporting repetitive task practice is the labor-intensive nature of these interventions. Difficulties in the provision of adequate training volumes for persons with stroke are well documented (Lang, Macdonald, & Gnip). Typical rehabilitation programs do not provide enough repetitions to elicit neuroplasticity. In a study of 36 outpatient therapy sessions for persons with strokes, Lang observed that subjects performed an average of 27 repetitions of functional activities during these session(Lang et al., 2007). This volume of intervention stands in stark contrast to training volumes of 500 to 600 repetitions of tasks performed by animal subjects in stroke rehabilitation studies (Kleim & Jones, 2008)and the 600 to 800 repetitions of activity per hour (Adamovich et al., 2005; Housman, Scott, & Reinkensmeyer, 2009; Krebs et al., 2008; Lum, Burgar, & Shor, 2004 Majmundar, and Van der Loos, 2002; Merians et al., 2011) reported in virtual rehabilitation and robotic studies. This ability to deliver intensive, repeated task practice has been one of the underlying hallmarks for the benefits of VR interventions.

To date, most of the studies investigating the therapeutic use of VR or VR/robotics have been superiority trials utilizing control comparison groups that received either no care or the usual standard of clinical care(Laver et al., 2011). However, three recently completed randomized control trials (RCT's), each testing a different, new, innovative therapeutic intervention (but not necessarily using virtual reality) have compared the putative intervention to both intensive comparison control groups and usual care groups and have thus provided us with important information regarding this issue. In both the LEAPS trial, body-weight supported treadmill training (BWSTT) in stroke patients (Duncan et al., 2011)and the SCILTS trial (Dobkin et al., 2006), BWSTT in persons with spinal cord injury, outcomes in terms of walking speed were equivalent between BWSTT and the equally intense comparison groups. In a study of patients, using robot-assisted therapy for upper limb impairment post–stroke, improvement in the Fugl-Meyer score was better for patients receiving robot-assistive therapy than those receiving usual care but worse than for those receiving intensive comparison therapy (Lo et al., 2009). There was a consistent pattern across these three studies, there was no difference between the experimental and the intensive control group but both of these conditions were better than usual care. Thus each study showed an effect not necessarily of the particular intervention but an effect of the intensity and increased dosage provided. Moreover, a cost-analysis done as part of the Lo et al. study did not yield significant cost differences between the robot-assisted therapy and the intensive comparison study. However, in the future one would expect that human supervised training will probably not become less costly, but that technology based treatment will thus effecting the cost equivalence.

There are several important take-away messages from these outcomes; 1) we can no longer design studies just with usual clinical care control groups; the comparison group must be of equal task intensity, and 2) the use of VR/robotics as a tool for the delivery of treatment intensity is effective but may not be superior to dose matched training without VR/robotics. If repetition and skill learning are important for motor learning and recovery of function we need to determine what VR technology can add over and above real-world task practice? What can training within an interactive virtual environment uniquely contribute to skill learning and improved motor control? It is vital to study how to utilize the potential sensory and perceptual affordances of virtual reality in the most beneficial way to provide improved motor learning experiences and lastly it is necessary to reflect on methods to ease the transition of these elements into the current therapeutic frameworks for clinical practice. Looking to the future we need to explore and develop rehabilitation applications of VR using such elements as task parameter and workspace scaling, on-line adaptive algorithms, modification of visual or proprioceptive feedback and grading of the volume/speed/location/complexity of the task. The overarching question is how we can manipulate these elements available through virtual environments to facilitate motor skill development and to effect excitability and functional connectivity of appropriate neural networks in the sensorimotor cortex.

3. MANIPULATION OF ELEMENTS IN VR TO FACILITATE MOTOR SKILL DEVELOPMENT

3.1 Activity Scaling

A skilled movement is characterized by consistency, stability, flexibility and adaptability. These features are achieved through practice-dependent changes in kinematic and force errors (Krakauer, 2006). With practice, one progresses through the stages of skill acquisition, eventually achieving a movement that is autonomous with fewer errors. Evidence suggests that repetitive practice resulting in "actual motor skill acquisition, or motor learning" may be a more potent stimulus for "driving representational plasticity in the primary motor cortex", than the simple repetition of activities that are well within the movement capabilities of a subject (Plautz, Milliken, & Nudo, 2000; Remple, Bruneau, VandenBerg, Goertzen, & Kleim, 2001). Thus activity scaling might be a critical issue related to neuroplasticity when considering the need for continuous skill development. Virtual environments are particularly well-suited to the systematic scaling of movements and task activities. The size of virtual workspaces, target sizes and activity speeds and forces can be increased in small gradients throughout the training period thus creating a gradually increasing level of difficulty for any task. Contrary to that, physical fatigue during large volume training sessions also presents challenges during motor training. Motor fatigue can be easily addressed in VR training through the same type of modifications (Fluet et al., 2012). Figure 1 shows the continuing changes in workspace volume over the course of the training period.

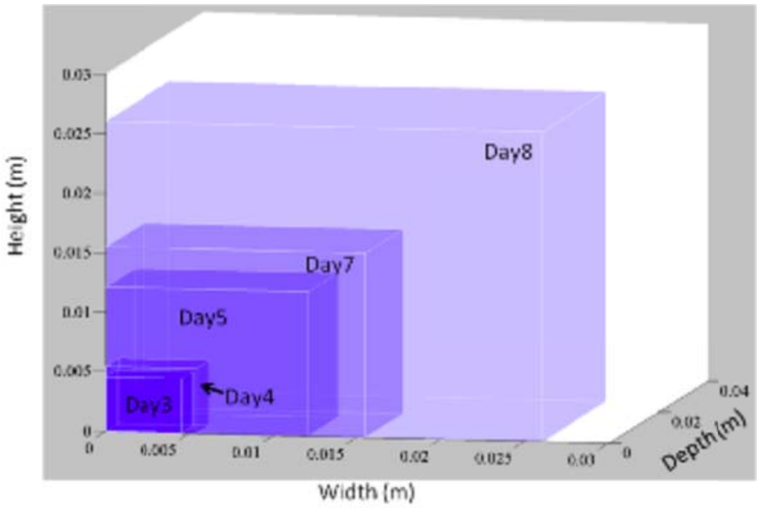

Figure 1. *Workspace expands gradually and continuously throughout the training period.*

It has been proposed that a favorable learning experience occurs when the task in neither too difficult nor too easy (Cameirao, Badia, Oller, & Verschure, 2010; Jack et al., 2001). In the Cameirao study, a reaching task in which the moving spheres move toward the participant who has to intercept them, the speed of the moving spheres, the interval between appearance of the spheres and the horizontal spread of the spheres (size of the workspace) were all manipulated based upon patient success rate. In this study the difficulty was increased by 10% when the participant intercepted more than 70% of the spheres and was decreased when less than 50% of the spheres were intercepted (Cameirao et al., 2010).

3.1.1 Activity Scaling Can Be Automated Using Online Adaptive Algorithms. These can provide a controlled, systematic method to gradually increase or decrease the demands of an activity. We use these algorithms in several of our simulations. The Virtual Piano simulation consists of a complete virtual piano that plays the appropriate notes as they are pressed by the virtual fingers while the subject is wearing an instrumented glove. This simulation was designed to help improve the ability of subjects post-stroke to move each finger in isolation (fractionation). Fractionation is calculated as the difference in the amount of flexion in the finger joints between the cued finger and the most flexed non-cued finger. Task difficulty is manipulated demanding more isolated finger flexion to elicit a key press as participants succeed and less fractionation if their performance diminishes. Initial target fractionation is calculated based on each subject's actual fractionation. If the actual fractionation reaches 90 percent of target fractionation, the next initial target fractionation is increased by eight percent of the previous target fractionation, if not, the next initial target fractionation is decreased by ten percent of previous target fractionation. Figure 2 shows an example of variation in the adjustable fractionation target based on an individual subject's actual ability to isolate their

fingers at each attempted key press. The blue line indicates the target fractionation, the red line is the actual fractionation and the green line indicates when key is successfully pressed. The left box shows the scenario when the subject reaches the target fractionation but the finger is not aligned with the piano correct key. The right box shows the scenario when the subject fails to reach the target fractionation and the target is lowered.

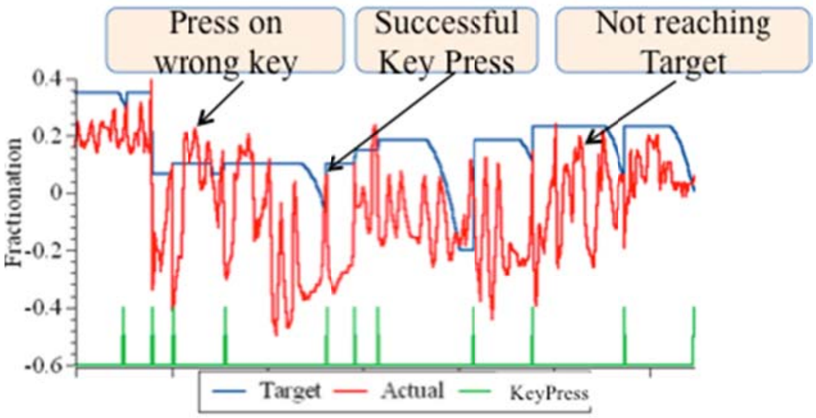

Figure 2. *Adjustable fractionation target based on an individual subject's actual ability to isolate their fingers at each attempted key press. Blue line indicates the target fractionation, red line indicates actual fractionation and green line indicates when key is successfully pressed. Left box shows the scenario when the subject reaches the target fractionation presses the wrong key. Right box shows the scenario when the subject fails to reach the target fractionation and the target is lowered.*

In a hammering task we utilize an algorithm that increases and decreases the target area of the cylinder to be hammered. The Hammer Task trains a combination of three-dimensional reaching with two different repetitive distal movements. In one version of the game the subjects reach towards a virtual wooden cylinder and then use finger extension or flexion to hammer the cylinders into the floor. The other version uses forearm supination and pronation to hammer the virtual wooden cylinders into a wall. The haptic effects allow the subject to feel the collision between the hammer and target cylinders as they are pushed through the floor or wall. Hammering sounds accompany collisions as well. The subjects receive feedback regarding their time to complete the series of hammering tasks. The programmed adaptive algorithm increases and decreases the target area of the cylinder to be hammered which in turn decreases and increases demands for hand stability that in turn is determined by the efficiency of elbow-shoulder coordination This adaptation is related to the time it takes the patient to hammer each cylinder.

3.2 Visual Motor Discordance

*3.2.1 Gain scaling.*We have also used scaling of the gain between the amount of movement of the subject's limb and of its virtual representation in several simulations. A gain algorithm is used to reinforce the amount of wrist rotation or finger extension needed to hammer the cylinders. If a subject is able to finish hammering the cylinder before it disappears, gain will decrease thus requiring a bigger range of wrist rotation/ finger extension to generate a displacement of the cylinder. A gain modification is also available in a Space Pong Game where we can decrease the gain from patient movement to virtual movement thus increasing the amount of finger movement required to produce paddle movement necessary to intercept the moving ball. We used this gain modification in a case study(Fluet et al., 2012) when the subject had difficulty controlling his fingers to produce effective paddle movement, evidenced by very low accuracy scores. After the first week of training, we decreased the gain from finger movement to paddle movement from 100% to 70% which increased the amount of finger movement required to produce paddle movement. Gain was increased by 15% on day 6 and back to 100% on day 9 of the trial as the subject's accuracy scores increased. Tunik and coworkers investigated the effect of gain manipulation on neural circuits. In an experiment in which the fingers of the hands in the VR display moved either 65%, 25% or 175% of the subjects' actual movement there was a definite effect of this visual manipulation on neural circuits. The discordance in gain between executed movement and observed feedback was associated with an increase in activation in contralateral M1. Analysis of movement kinematics confirmed that actual movement performance did not confound this result. A parsimonious explanation is that both low-gain feedback (25% and 65% conditions) and high-gain feedback (175% condition) up-regulated neural activity in the motor system as if M1 was acting to reduce the

discrepancy between the intended action and the feedback indicating the finger is not moving as expected. Two complementary approaches to these manipulations utilize large patient movements compared to avatar movement for up-regulating the motor cortex or large avatar movements when compared to patient movement that allow patients with very little active movement to generate purposeful avatar movements with their paretic upper extremity (Bagce, Saleh, Adamovich, & Tunik; Tunik, Saleh, & Adamovich, 2012)

*3.2.2 Error augmentation.*This is another example of an adaptive training method that uses visual distortions. In this paradigm, subjects post-stroke use their hemiparetic arm that is supported by a robot to follow a trajectory path outlined on the computer screen by the therapist. The computer measures and magnifies the subject's movement error in relation to the preferred trajectory, thereby trying to force the subject to improve their control. Error augmentation can be provided both visually and by forces generated by the robot. Although the clinical measures showed mixed results, and did not indicate functional gains, the results indicate that error augmentation was superior to an equal dosing of simple massed practice for skill development (Abdollahi et al., 2011; Patton, Stoykov, Kovic, & Mussa-Ivaldi, 2006).

4. COMMERICALLY AVAILABLE VR EXERCISE SYSTEMS

Long term adherence to home training and exercise programs over time is an important consideration in the management of patients with permanent disabilities. The effectiveness of gaming based activities for maintaining high levels of attention and motivation with the goal of supporting these behaviors has been cited (Saposnik & Levin, 2011). Virtual environments are particularly well suited for delivering game action (S. V. Adamovich, Fluet, Tunik, & Merians, 2009). We have recently developed a library of therapeutic gaming activities that utilize interactive environments and a six-degree-of-freedom robotic arm. In a Spaceship game (Figure 3), subjects navigate a space ship in the presence of various objects moving towards the subject, with the task to avoid collisions with objects-invaders and intercept "good" objects (Figure 3). We are able to adjust the speed of the moving space ships and objects, the size of the workspace and objects and the objects density to gradually increase the difficulty of the motor task. Targets can be concentrated in quadrants to emphasize range of movement to a specific area of the patient's reachable space. In addition, we are able to manipulate various haptic effects provided by the robotic arm that subjects move in 3D space during the gaming activity: the magnitude of impact absorbed when colliding with invaders, the amount of anti-gravity arm support, and the amount of damping provided by the robot to stabilize the paretic arm, among others.

Figure 3. *Screen Shot Spaceship Game.*

Two lines of inquiry, one utilizing lab-based customized systems and another examining consumer gaming technology for the rehabilitation of persons with disabilities has developed over several years. It is clear that lab-based systems are significantly more flexible and therefore usable for a larger percentage of persons with disabilities. The haptic component available in lab-based systems is a useful tool in the beginning of rehabilitation when one is trying to initiate useful movement. In addition to not being able to be modified for individual patient impairment levels, the commercial gaming systems cannot provide kinematic outcome

data. However, the affordability of consumer oriented systems and the entertainment values that can be delivered by these platforms bring considerable advantages. The design of rehabilitation activities for consumer platforms by engineers and therapists with experience accommodating the abilities and goals of persons with disabilities is an area that needs to be explored for rehabilitation gaming to remain relevant. One can envision a rehabilitation sequence in which the patient progresses from using complex adaptable lab-based systems during the in-patient/outpatient phase of rehabilitation to continued use of home-based commercial systems similar to the concept of physical fitness and life-long exercise.

5. SENSITIVITY OF OUTCOME MEASURES

The variety of outcome measures currently being used in virtual reality/robotic research of arm and hand rehabilitation address outcomes at the three levels of function determined by the World Health Organization International Classification of Functioning, Disability and Health to describe health and function. The most common measures used are the Fugl-Meyer (FM), which tests impairments at the body structure level; the Action Research Arm Test (ARAT), Wolf Motor Function Test, Jebsen Test of Hand Function and the Nine-Hole Peg Test all at the activity level and the Stroke Impact Scale that tests social participation. Given the heterogeneity of the populations most often served by the VR interventions and the wide variation in patient outcomes, pertinent questions are whether these measures are sensitive enough to provide measurable evidence of the patient’s progress and functional change and how can we further expand our ability to understand the impact of these newer interventions and their effect on long-term function. In a case study assessing long term changes in paretic upper limb function, (van Kordelaar et al., 2012) et al. found that clinical assessments indicated that motor function (measured by FM) and functional abilities (measured by ARAT) plateaued by about 8 weeks while the kinematic outcomes demonstrated ongoing recovery for 6 months. The authors suggested that standard clinical assessments used in clinical trials may not be sufficiently sensitive to capture further improvement due to a ceiling effect. The complex nature of neurorehabilitation may call for an integration or combination of quantitative and qualitative data to maximize the strength and minimize the weaknesses of each form of measurement and to develop a more complete understanding of this complex phenomenon.

6. CONCLUSION

In conclusion, several areas of study are indicated to continue the development of VR environments and interventions to foster beneficial changes in motor rehabilitation. The first would be to expand the study of virtual interventions to include persons in the acute phase of recovery. Further, continued study of the manipulation of task difficulty using either on-line algorithms or therapist mediated modifications and the use of visuomotor discordance including manipulation of the ratio of active patient movement to avatar movement are areas to be studied to further determine the unique contributions that practicing in virtual environments can make in motor rehabilitation. Finally, further evolution of our clinical outcome measures is sorely needed. In addition to the need for more sensitive clinical measures, studies of interventions using virtual reality/robotics should include multiple types of measurements, possibly mixed method research designs, repeated kinematic analyses and imaging studies in order to understand recovery at both the functional level and the neural level.

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Robotic/virtual reality intervention program individualized to meet the specific sensorimotor impairments of an individual patient: a case study

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ABSTRACT

A majority of studies examining repetitive task practice facilitated by robots for the treatment of upper extremity paresis utilize standardized protocols applied to large groups. Others utilize interventions tailored to subjects but don't describe the clinical decision making process utilized to develop and modify interventions. This study will describe a virtually simulated, robot-based intervention customized to match the goals and clinical presentation of a gentleman with upper extremity hemiparesis secondary to stroke. MP, the subject of this case, is an 85 year-old man with left hemiparesis secondary to an intracerebral hemorrhage five years prior to examination. Outcomes were measured before and after a one month period of home therapy and after a one month virtually simulated, robotic intervention. The intervention was designed to address specific impairments identified during his PT examination. When necessary, activities were modified based on MP's response to his first week of treatment. MP's home training program produced a 3 second decline in Wolf Motor Function Test (WMFT) time and a 5 second improvement in Jebsen Test of Hand Function (JTHF) time. He demonstrated an additional 35 second improvement in JTHF and an additional 44 second improvement in WMFT subsequent to the robotic training intervention. 24 hour activity measurement and the Hand and Activities of Daily Living scales of the Stroke Impact Scale improved following the robotic intervention Based on his responses to training we feel that we have established that, a customized program of virtually simulated, robotically facilitated rehabilitation was feasible and resulted in larger improvements than an intensive home training program in several measurements of upper extremity function in our patient with chronic hemiparesis.

1. INTRODUCTION

Robotics and virtual environments are being combined to facilitate the intensity and volume requirements of RTP (Kwakkel, Kollen, & Krebs, 2007; A. S. Merians et al.)insert date. To date, the majority of these interventions have been studied using standardized experimental protocols in groups of patients, using a uniform set of upper arm movements and simulations (Mehrholz, Platz, Kugler, & Pohl, 2008; Patton, Dawe, Scharver, Mussa-Ivaldi, & Kenyon, 2004)Several systems have attempted to individualize the interventions via more adaptable physical interfaces (Johnson, Feng, Johnson, & Winters, 2007) adapted tasks (Cameirao, Badia, Oller, & Verschure)insert date, adapted feedback or physical components of the system (Lehrer, Chen, Duff, S, & Rikakis).insert date Similarly, in our previously published studies using the NJIT-RAVR and NJIT Track/Glove systems, the experimental protocols used a standardized approach applied uniformly to all included patients, without regard to individual therapeutic goals, specific impairments or responses to the intervention (A. Merians et al., 2010; A. S. Merians et al.). This case report attempts to describe a clinically relevant implementation of the system using an intervention protocol designed specifically for an individual patient, thus adding a new dimension to the body of work previously published on robotically assisted virtual reality interventions. Simulations were chosen that addressed the motor impairments identified during the subject's examination that limited his ability to perform specific goal activities. The simulations were configured in terms of required movement patterns, speed, and range of motion to maximize the subject's ability to benefit from them. The simulations were then further modified based on his responses to the first few training sessions This case study

compares the outcomes of one month (12 sessions) of home physical and occupational therapy to one month (12 sessions) of individualized robotic/virtual reality training.

2. METHODS

2.1 System

Two robotically facilitated virtual rehabilitation systems, the NJIT-RAVR system and the NJIT TrackGlove system were used. These two systems when used sequentially in a training session have the capability of training individual fingers of the hand and all motions of the arm. It is fully integrated with a library of twelve activity-based virtual reality gaming and task simulations. For MP we chose 6 of the simulations, Virtual Piano, Space Pong, two modes of Hammering Task, Cup Placement and Reach-to-Touch. A CyberGlove© (Immersion) was used for hand tracking. Two of the six simulations use the Flock of Birds (Ascension Technologies) motion sensors for arm tracking and the other four use the Haptic Master robot (Moog FCS Corporation). Simulations were programmed using either C++/OpenGL, the Virtools software package with the VR Pack plug-in (Dassault Systemes) or the Haptic Master's Application Programming Interface. One game was adapted from an existing Pong game(Taylor et al., 2001) in which the game control was transferred from the computer mouse to the CyberGlove.

2.2 Subject

MP is an 85 year-old gentleman with left hemiparesis secondary to an intracerebral hemorrhage five years prior to his examination. He uses a power wheelchair for mobility but is able to walk short distances and requires moderate assistance for activities of daily living.

2.3 Outcome Measures

Outcomes measures included kinematic analysis of trained movements utilizing data collected daily by the robotic systems such as finger angles, duration of the combined transport and hammering phase for each cylinder, smoothness of the movement trajectory and deviation of the endpoint obtained during the hammer task and accuracy, duration, and fractionation, (ability to isolate the movement of each finger) obtained during the virtual piano task. Clinical measures used to test at the body structure and activity levels consisted of the Upper Extremity Fugl-Meyer (UEFMA) and three timed tests, the Jebsen Test of Hand Function (JTHF), the Wolf Motor Function Test (WMFT), and the Nine Hole Peg Test (NHPT)(Jebsen, Taylor, Trieschmann, Trotter, & Howard, 1969; Mathiowetz, Volland, Kashman, & Weber, 1985; Wolf et al., 2001) In addition the Modified Functional Reach(Katz-Leurer, Fisher, Neeb, Schwartz, & Carmeli, 2009) was used to evaluate our ability to improve MP's ability to bend at the waist while reaching forward, a specific goal he described during his examination. We tested for changes at the activity level outside the laboratory by collecting UE accelerometer data for 24 hours immediately after each testing session. Metrics included total vertical plane activity (Lang, Wagner, Edwards, & Dromerick, 2007), the ratio of impaired to unimpaired UE vertical plane activity (Uswatte, Taub, Morris, Vignolo, & McCulloch, 2005) and total roll plane activity. Roll plane motion was chosen because pronation and supination movements tend to be a smaller component of non-purposeful movement than the vertical flexion activity measured in other studies (Fan, He, & Tillery, 2006). To test for changes at the participation level, MP completed the hand, mobility, activities of daily living and social participation subscales of the Stroke Impact Scale (SIS)(Duncan et al., 1999).

2.4 Procedure and Customized Intervention

Prior to the VR/robotic intervention MP received combined physical and occupational therapy in his home focusing on ambulation, balance, transfers, and upper extremity function. Data was collected four weeks before (pre-test1) and immediately after the one-month (12 sessions) period of home therapy (pre-test 2). One month (12 sessions) of VR/robot training began four days after the second data collection. The third data collection (post-test) was performed after completion of VR training. During his examination MP described the following goals 1) Improved use of his arm and hand during transfers 2) Improved use of his arm during dressing 3)Improved use of his hand during eating, grooming and computer activities. MP's goals and the results of his examination were used to choose simulations and strategies for their implementation. Over four weeks, of VR training, MP performed twelve sessions of training with the NJIT-RAVR system and the NJIT TrackGlove system, which are described in detail elsewhere (Adamovich, Fluet, Mathai, et al., 2009; Adamovich, Fluet, Merians, Mathai, & Qiu, 2009) MP performed six different simulations at all of the sessions.

2.5 Simulations

MP had difficulty manipulating small objects due to an inability to flex fingers individually. We utilized the Virtual piano (Fig 1a) trainer to address this impairment. MP combined the performance of scales and drills with

his hand stationary and short songs with his hand moving along the length of the keyboard. The simulation measures the difference between the metacarpophalngeal angle of the finger cued to press a key and the average of the other fingers. When a target difference is exceeded, a note plays. This target is controlled by an algorithm using the subject's prior performance. MP made poor progress during training with this simulation over the first three days of the intervention (Fig 1 Right Panel). We added the CyberGrasp, an exoskeleton robot, to help MP maintain extension of the non-cued fingers during his attempts to bend the cued finger (Fig 1 Middle Panel). The CyberGrasp was during the entire session during week two and during the first five minutes of each session with the Virtual piano trainer, followed by a fifteen minute block without the robot during week three. MP trained without the CyberGrasp during week four. This strategy was effective for improving finger individuation over the final three weeks (Fig 1 Right Panel).

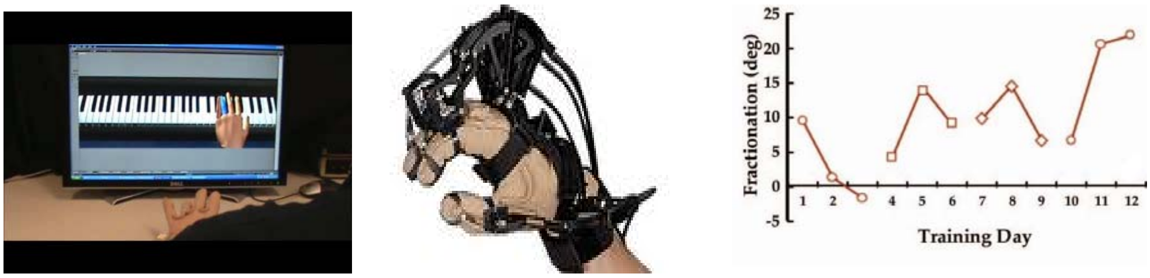

Figure 1. *Left Panel: Subject performing Virtual Piano Trainer simulation. Center: CyberGrasp™ worn over a CyberGlove™ (Immersion Technologies, USA) as used in this case .Right: Daily averages for fractionation score demonstrated by MP.*

MP also reported difficulty controlling the aperture of his hand as he attempted to grasp objects. We utilized the Space Pong simulation to address this impairment. MP played this pong game using opening and closing of his hand to control the paddle. Initially MP made no improvement in his performance of this game. After Week One MP's therapist decreased the ratio of actual movement to virtual movement from 100% to 70% which increased the amount of finger movement required to produce paddle movement. This allowed MP to control his paddle more accurately. Gain was increased by 15% to 85% on day 6 and back to 100% for the last week of the trial as MP's accuracy scores increased. (Fig.2)

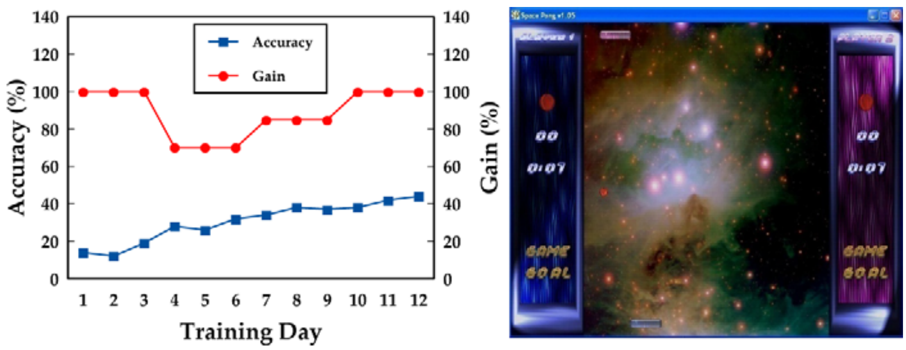

Figure 2. *Right Panel Daily averages for accuracy (Blue boxes) and gain which is the ratio of finger movement to avatar movement. Left: Screenshot of Space Pong (©Steve Taylor, 2003) Need to insert Fig 2*

During his examination MP had difficulty handling objects that were more than 60 centimeters from his body due to difficulty stabilizing his arm and hand with his shoulder elevated. We implemented the Hammer simulation to address this impairment (Fig 3 Left Panel). MP moved a virtual hammer over virtual pegs in a three dimensional space and then hammered them using a repetitive finger extension-flexion movement. We used an algorithm that modified the area of the top of the target, to reinforce UE stabilizing behavior. We increased target size, which decreases stability demands, when MP hammered targets efficiently and decreased the area, which increases the need to stabilize when he finished targets quickly. MP made steady improvements in this construct during the first two weeks of the trial and maintained them despite increases in the weight of his arm supported during this simulation (Fig 3 Right Panel). In addition to shaping proximal stabilization we also gradually increased the percentage of the weight of arm support that was provided during this activity. This percentage was increased when MP averaged less than 15 seconds to hammer pegs over the course of an entire training day (Fig 3 Right Panel).

MP demonstrated difficulty performing activities requiring pronation of his forearm. We utilized a modified version of the hammer simulation described above to train pronation in varying degrees of elbow extension and shoulder flexion, with the arm fixed in space during a set. Fixing the arm decreased the load MP needed to stabilize with his shoulder musculature. We attempted to utilize an algorithm that modified the proportion of patient movement to avatar movement. The therapist decreased the amount of pronation required to swing the hammer in order to increase MP's success rate. This approach was successful during week two but the gains were not maintained during week three, when the pronation to hammer movement ratio was returned to normal. A second attempt was made using this approach during week three with little success (Fig. 4)

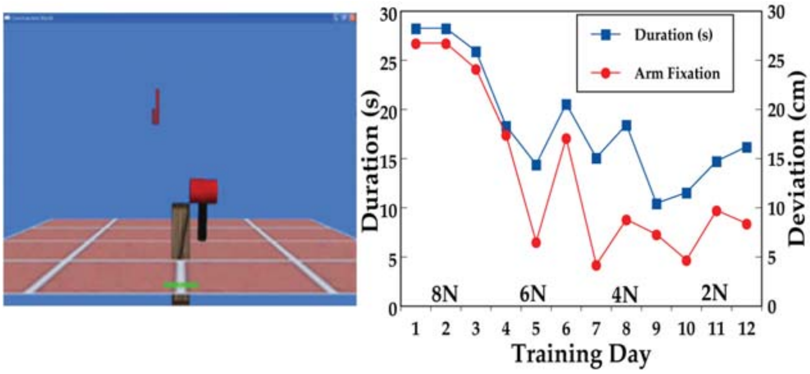

Figure 3. *Left Panel: Screenshot of Hammer simulation. Right:Daily averages for time to hammer ten targets (Blue boxes) and arm fixation scores (Red Circles) lower numbers=less extraneous movement. Note that assistive forces decrease every three days.*

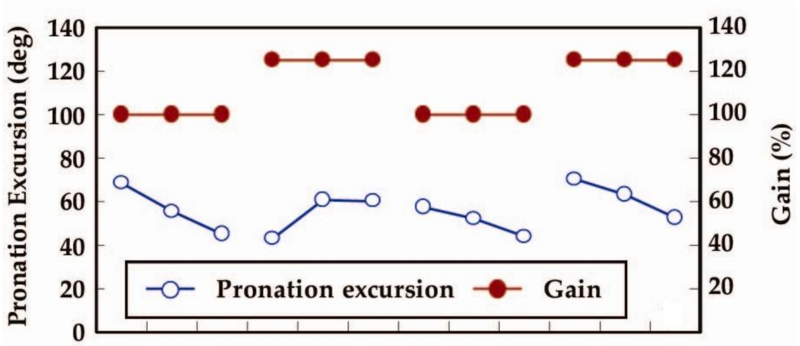

Figure 4. *Description of daily averages in pronation active range of motion and gain which is the ratio of forearm movement to avatar movement.*

During his examination MP had difficulty reaching and bending at the waist in a coordinated fashion. We utilized the Cup Reaching simulation to improve this ability (Fig 5 Left Panel). To perform this simulation, MP attached his hand to a virtual cup resting on a table near his body, reached forward and placed it in one of nine spaces on a haptically rendered shelf. We set the height, width and distance of the shelves based on MP's maximum reaching excursions .We calibrated the workspace reaching weekly, with MP's trunk moving freely and encouraged him to flex at the trunk to increase his forward reaching distance. We started each week of training in 65% of the maximum reaching space and increased the percentage if MP's time to place a set of nine cups decreased on a given day. The volume of the work-space and average time to place nine cups for each day is summarized in Fig 5 Right Panel).

We utilized a second simulation Reach-to-Touch to also address forward reaching impairments focusing on the shoulder and elbow through three-dimensional reaching movements. In this simulation, MP was encouraged to keep his trunk still during the reaching task and was cued to sit back if he bent at the waist to complete a movement. A similar schedule of workspace calibration was followed, calibrating every third day throughout the intervention using the same protocol used for the Cup Reaching simulation. MP's time to perform this simulation decreased steadily despite systematic increases in the size of the reaching movements he performed.

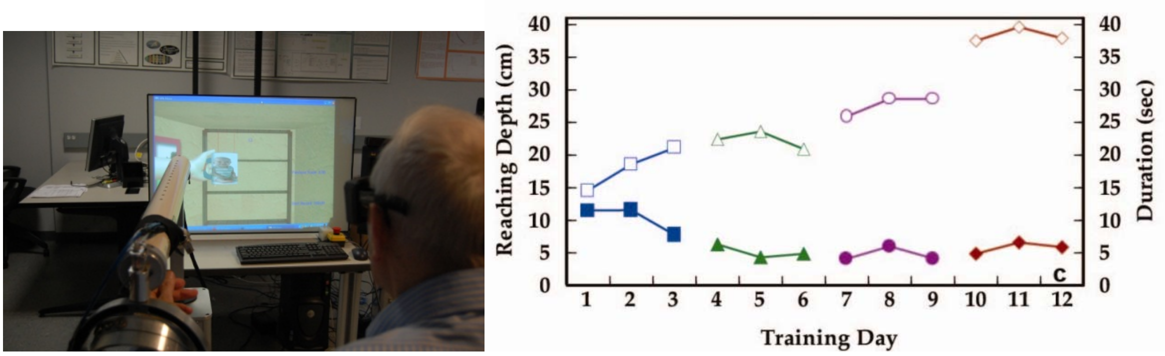

Figure 5. *Left Panel: Subject performing Cup Reaching simulation. Right:Daily averages for reaching depth (open figures) and time to move ten cups (closed figures). Workspace was calibrated every three days.*

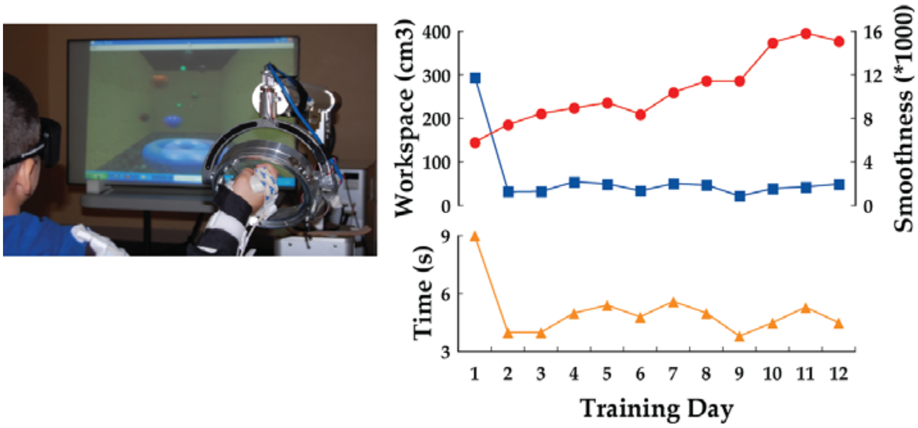

Figure 6. *Left*: *Subject performing the reach-touch simulation. Right: Daily averages for workspace volume (Red Circles,) smoothness (Blue Boxes) and the average time to complete a set of ten targets.*

3. RESULTS

MP did not make changes in UEFMA subsequent to the month of home PT/OT (pre-test 1 to pre-test 2) but demonstrated a four-point improvement in the UEFMA subsequent to the twelve sessions of robotically facilitated VR training (pre-test to-post-test). MP achieved an inconsequential, 5-second improvement in JTHF time following home therapy but demonstrated a 35 second improvement following the robot/vr intervention. MP performed three seconds slower on the WMFT following his period of home training but made a substantial 44-second improvement subsequent to robotic training. MP's NHPT time improved by fourteen seconds following robotic training.

All three of the twenty-four hour activity measurements collected before and after the VR/-robotic training improved as well. Active vertical plane movement increased (26 minutes) which is comparable to changes demonstrated during an acute rehabilitation stay (Lang et al., 2007). Time performing pronation and supination increased 13 minutes. The ratio of impaired arm movement to unimpaired arm movement increased from 41 to 51 percent, Subjects in a CIMT study of subjects post stroke made a similar ten percentage point increase in UE ratio (Uswatte et al., 2000)**.** MP demonstrated an improvement of seven points on the hand scale of the SIS, six points in the social participation scale, and eight points in the ADL scale. MP's caregivers also reported a dramatic increase in MP's ability to participate in pull-to-stand transfers with his impaired UE.

4. DISCUSSION

The clinical, kinematic and 24-hour real-world activity monitoring demonstrate the positive outcomes from this case study showing potential advantages in this personalized robotic/VR intervention. MP made substantial improvement in the JTHF and WMFT. Each of these tests contains several items that involve object manipulation and transport with accuracy demands beyond those of a gross grasp. In addition MP made small

improvements in ADL function and demonstrated improvements in all four measurements of impaired arm use as measured by activity monitor. Despite these changes, MP demonstrated no improvements in the wrist-hand portion of the UEFMA. A large majority of the robotic intervention studies for persons with stroke utilize the UEFMA as their primary outcome measure and a lack improvement in wrist and hand function is cited as a limitation of robotic UE interventions(Kwakkel et al., 2007). We feel that MP's pattern of improvement may suggest a lack of sensitivity in the UEFMA for determining changes in wrist and hand function.

Multiple authors espouse limiting trunk movement as a method for decreasing abnormal and inefficient compensatory trunk movement during reaching activities (Levin, Michaelsen, Cirstea, & Roby-Brami, 2002; Michaelsen, Dannenbaum, & Levin, 2006). Others cite evidence of coordination of trunk and arm movement in normal motor control (Rossi, Mitnitski, & Feldman, 2002). Poorly coordinated trunk and UE movement was an impairment that we targeted for MP's intervention by utilizing large excursion reaches and encouraging MP to use trunk movement to accomplish them. MP made substantial improvements in his ability to perform this movement during training and as measured during the Modified Functional Reach test. MP's caregivers also commented that he was better able to transfer because of improved forward weight shift and increased ability to reach forward for grab bars. We attempted to balance the development of maladaptive reaching strategies by presenting MP with two more reaching activities (Hammer simulation and Bubble Explosion simulation) that trained reaching without trunk movement.

Modifications in approach to training were made based on therapist observation in three of the six simulations (Piano Trainer, Space Pong and Cup Reach), all of which resulted in substantial improvements in MP's performance of the simulations. The training protocols described in a large majority of the investigations of rehabilitation robotics involve set protocols that do not vary significantly based on subject response(Kwakkel et al., 2007). This may result in an underestimation of the potential benefits of this technology as the training programs utilized in these studies fail to leverage the flexibility of robotics and virtual environments as rehabilitation platforms.

The manipulation of the relationship between participant and avatar movement during virtually simulated rehabilitation activities has been examined by Bagce et al(Bagce, Saleh, Adamovich, & Tunik, 2012). In their study, conditions in which the avatar moved less than the participants' actual movement resulted in increased levels of cortical activation, and decreased levels of cortical activation when avatar movement exceeded the actual amount of movement performed by the participant. Interestingly, MP demonstrated improved levels of motor performance during performance of Space Pong, which presented MP with very small avatar movement compared to his actual movements and no improvements in pronation during performance of the Hammer Task in which we presented large avatar movements compared to MP's actual movement. This technique has been used previously to transform tiny amounts of active movement into "meaningful" movements in an attempt to improve motor learning / neuroplasticity. (Kleim et al., 2002).

Two of the simulations utilized in this study incorporate adaptive algorithms that scaled task parameters based on MP's performance in real time as MP performed training tasks. The Hammer Task simulation gradually decreased the area of the target as MP improved his ability to stabilize his hand and the Piano Trainer simulation required progressively larger levels of individuated finger flexion to strike piano keys based on MP's performance of the previous ten repetitions. Brief discussions of our approach to modifying task parameters in response to a participant's performance have been described elsewhere (Adamovich, et al., 2009; Merians, et al., 2011) and a more in depth discussion of this approach has been presented by Cameriao et al. (Cameirao, Bermudez, Duarte Oller, & Verschure, 2009). It is important to note that this technique has the potential for making rehabilitation activities more effective because high levels of intensity are maintained and more cost effective because it decreases the need for direct supervision of a therapist to make minor modifications of task parameters. With the feasibility of this approach well established, further investigations comparing the effectiveness of adaptively scaled activities to more traditionally presented activities is indicated.

5. CONCLUSIONS

This case report clearly demonstrates the flexibility of a robotic and virtual reality rehabilitation system and its ability to personalize a program of robotically facilitated repetitive task practice. This individualized application of VR training has not been adequately evaluated by the standardized treatment protocols reported in the existing literature. Further evaluation of this approach will be critical for the translation of VR training from the laboratory to widespread clinical practice.

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Can a home based virtual reality system improve the opportunity for rehabilitation of the upper limb following stroke?

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ABSTRACT

Many stroke survivors fail to regain functional use of their impaired upper limb yet access to the rehabilitation required is limited. One route through which this may be achieved is through the adoption of virtual reality and interactive video gaming. We have been developing a home based system that employs infra red capture to translate the position of the hand, fingers and thumb into game play but do the patients actually use it to the recommended level and if not, why not? Performance data collected by the software from three participants allocated to the intervention group in a feasibility RCT indicate that the pattern of play is variable and can fall far short of the recommendations participants were given. Interviews with participants at the end of the intervention and observations by the research team indicate the barriers to recommended use but also some of the characteristics of the intervention that demonstrate its potential for improving the opportunity for rehabilitation of the upper limb following stroke.

1. INTRODUCTION

Many stroke survivors fail to regain functional use of their impaired upper limb (Feys et al, 1998). Both meta-analyses and systematic reviews have shown that early intensive (Kwakkel et al., 2004), task specific (van Peppen et al, 2004) practice for a prolonged period of time (van der Lee et al, 2001) facilitates motor recovery. There are no clear recommendations on how much practice a patient should engage in either in terms of duration of rehabilitation or number of repetitions. Most available evidence is on duration. A meta-analysis by Kwakkel et al (2004) concluded that therapy input is augmented at least 16 hours within the first 6 months after stroke. However, reviewing studies where constraints were applied to the less affected arm and thus forcing patients to use the affected arm led them to suggest a benefit from a high dose over a shorter period of time, specifically 6 hours per day during 2 weeks (i.e., augmentation of 60 hours). They also reported that there was no ceiling effect for therapeutic intensity, beyond which no further response is observed.

In view of the evidence, in the UK the National Clinical Guidelines for Stroke recommend that patients should undergo as much therapy appropriate to their needs as they are willing and able to tolerate (3.13.1). However, access to rehabilitation while in hospital is limited and once home contact with a therapist is low. Even if patients are sent home with exercises, adherence to treatment is poor: 50%–55% of patients with chronic medical conditions fail to adequately adhere to treatment regimens (Carter, Taylor & Levenson, 2003). Clay and Hopps (2003) suggest that one factor that contributes to non-adherence is the perception of treatment regimens as rigid and immutable. Their effectiveness is irrelevant if they exhaust patients' capabilities and motivation. Adherence could be improved if treatments are designed that are amenable or adaptable to more appropriately fit into the lifestyles and limitations of patients and their families.

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One route through which this may be achieved is through the adoption of virtual reality and interactive video gaming which have emerged as new treatment approaches in stroke rehabilitation (Laver et al, 2011). Interfacing virtual reality games with robotic arms (eg Merians et al, 2010) exploits the benefits of these latter systems which were found by Kwakkel, Kollen & Krebs (2008) in a systematic review to have significant improvement in upper limb motor function. However, their cost, location in a lab, hospital or health centre and requirement for specialist technical support limit their availability for most stroke patients. The more recent appearance of commercial gaming consoles such as the Wii and Kinect have led to their adoption by therapists in clinical settings (eg Saposnik et al 2010). These consoles have the advantages of mass acceptability, easily perceived feedback and most importantly affordability for unrestricted home use. However, the games are not specifically designed for therapeutic use and while some of the games encourage movements of the upper limb, neither system captures the movement of the fingers.

We have been developing a home based system that employs infra red capture to translate the position of the hand, fingers and thumb into game play (Standen et al, 2010). Four games with varying levels of challenge encourage the movements of the hand that underpin activities of daily living. The equipment is left with participants for eight weeks and they are given recommendations on the frequency and duration of use. We are currently running a feasibility randomised control study in preparation for an evaluation of the effectiveness of the intervention. Effectiveness will be measured in terms of changes in upper limb function but it is also necessary to know whether such an intervention results in participants achieving a duration of rehabilitation that approaches the recommendations from previous research. The software collects data on frequency and duration of use, what games are played, what levels used and scores obtained. These data allow adherence to the recommendations to be examined. For the feasibility study up to 60 patients aged 18 or over are being recruited, who have a confirmed diagnosis of stroke and who still have residual upper limb dysfunction.

This paper examines data collected so far on participants who have currently completed the intervention to answer the following questions:

- How close to the recommended duration were participants using the equipment?
- How close to the recommended frequency were participants using the equipment?

2. METHODS

2.1 Design

The equipment is being evaluated using a two group randomised control trial to compare it with usual care. Outcome measures are collected at baseline and after 4 and 8 weeks.

2.2. Participants

Data are presented on three of the participants who have been allocated to the intervention group and who have completed their intervention.

2.3 The Virtual Glove

The virtual glove consists of a hand-mounted power unit, with four infra red light emitting diodes (LEDs) mounted on the user's finger tips (see Figure 1). The LEDs are tracked using one or two Nintendo Wiimotes mounted by the PC on which the games are displayed to translate the location of the user's hand, fingers and thumb in 3D space. In order to play the four games specially written, users have to perform the movements of reach to grasp, grasp and release, pronation and supination that are necessary to effect many activities of daily living..

2.4 Games

Four games have been developed based on suggestions received from the Nottingham Stroke Research Consumer group, participants in the pilot study and members of the project steering group (Standen et al, 2010). Figures 2 to 5 show screenshots from each of the games. Each game has different levels varying in the standard of the movement required to achieve a score, the speed at which events occur and with which responses are required as well as in complexity of challenge in order to keep the participants motivated to continue to use the system but to ensure that they can achieve some success. Participants' scores are displayed on the screen at the end of a game and there is a permanent visual display of their progress in terms of scores and levels played. A log of when the system is in use is collected by the computer as well as what games are being played and what scores the user obtains.

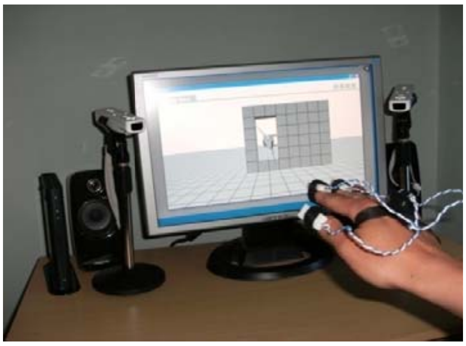

Figure 1. *The virtual glove.*

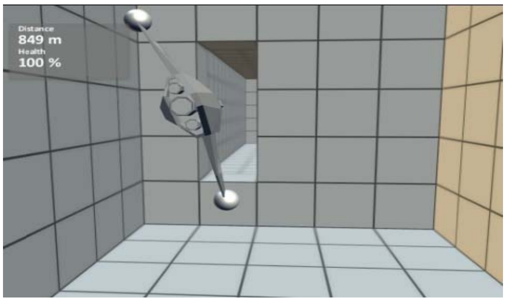

Figure 2. *Space Race.*

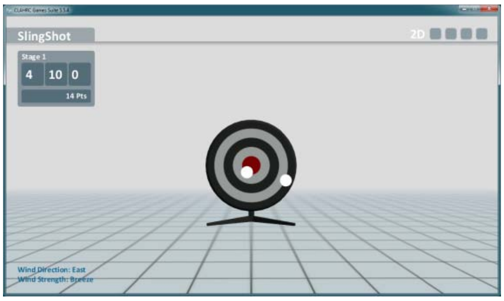

Figure 3. *Sponge ball.*

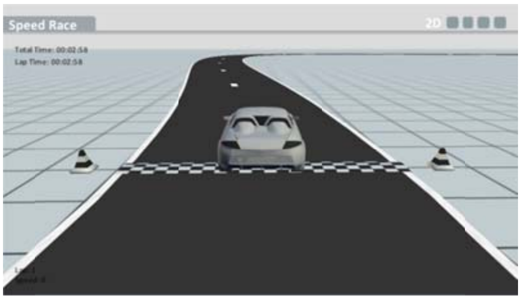

Figure 4. *Balloon Pop.*

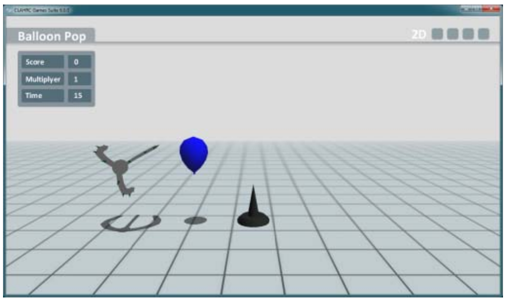

Figure 5. *Speed Race.*

2.5 Intervention

Participants are randomly allocated to either the intervention group or the control group. Those participants in the intervention group have the virtual glove in their homes for a period of 8 weeks and are advised to use the system for 20 minutes 3 times a day for 8 weeks.

2.6 Outcome Measures

Wolf motor functions test, a measure of upper limb functioning; the Nine-Hole Peg Test, a test of fine motor co-ordination; the Motor Activity Log, to record daily use of the affected arm and the Nottingham Extended Activities of Daily Living, a measure of functional ability that is commonly used in studies of stroke rehabilitation. For the intervention group the frequency of use of the equipment is collected by the software.

2.7 Procedure

Participants are recruited from the community stroke teams. Baseline assessments are collected during a home visit before the participant is randomly allocated to the intervention or control group. For those assigned to the intervention group, when the equipment is delivered and set up it is demonstrated to them and their carer. A member of the research team then uses the equipment with the participant and observes them using it independently. The researcher then arranges to return to repeat this demonstration until they feel that the participant has understood how to use the equipment or that there is a carer who understands how to use it. After four weeks all participants are visited at home for completion of the outcome measures. At the end of the intervention, after the equipment has been collected, a short semi-structured interview is carried out with the participant and any carers to determine their experience of using the equipment, barriers to using it

in the recommended way and to the recommended levels. Interviews are audio recorded. All participants are assessed at eight weeks post randomisation.

3. RESULTS

15 participants have been recruited so far of whom 8 were allocated to the intervention group. Data from 3 are presented below.

- 79 year old woman eight weeks post stroke with dominant (right) upper limb affected. Lives alone. She had finished with the Community Stroke Team so had no other weekly appointments. She was getting back to driving, but typically wasn't going anywhere most days. She did however tend to have a sleep in the afternoon. She has a laptop but had not used it since her stroke as she could not manage the mouse pad.
- 54 year old man 16 weeks post stroke dominant (right) upper limb affected. Has young children at school and spends a lot of time with them taking them to sporting activities. He has time in the day when the children are at school but attends a stroke exercise group on Fridays and has many other appointments. He is very experienced playing computer games and using computers in general, at home they have a wii, xbox and a laptop all of which are regularly used.
- 53 year old woman, 19 weeks post stroke dominant (right) upper limb affected. Lives alone. Was starting back at work for 4 hours twice a week. Only has the speech and language therapist visiting her at home now. She has a laptop at home which she uses regularly especially to email family. She was very motivated as she knew she only had the computer for 4 weeks due to her holidays

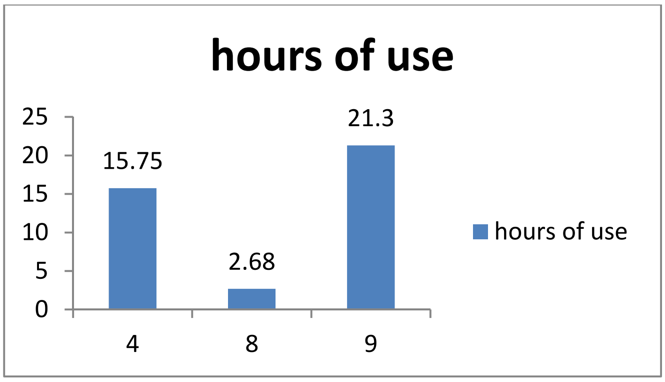

Figure 6. *Total number of hours in which the equipment was used by the three example participants.*

3.1 Performance Data

3.1.1 Duration of use Participants were advised to use the equipment for 20 minutes 3 times a day for 8 weeks. At 7 hours a week, this would have produced a total duration of use of 56 hours. Figure 6 shows the total duration of use for the three participants whose data have been analysed so far. Hours of use ranged from 2.68 to 21.3 far short of the recommended 56 hours. However the third participant went on holiday after four weeks so achieved the 21.3 hours total in half the recommended period, not far below the 28 hours that would be expected at the recommended frequency and duration of play.

3.1.2 Number of days on which equipment was used. Another way to determine whether the recommendations on use are being followed was to examine the number of days on which the equipment was in use at all. Figure 7 shows the total number of days on which the equipment was in use by the three example participants and these range from 9 to 45 days. Obviously the low number of days that participant 8 used the equipment can explain the low number of hours he returned in Figure 6. However, although participant 4 used the equipment for less than a third of the recommended duration, she was actually using it on most of the days that it was in her house. Participant 9 used the equipment on every day that it was in her house.

3.1.3 Mean duration only for days with any play. If participants were not using the equipment every day, how close to the recommended hour a day were they using it on the days when they did play? Figure 8 shows the median daily duration of use in minutes on days when the equipment was in use together with minimum, first quartile, median, third quartile, and maximum duration. Even for participant number 9 the median duration is less than 60 minutes although the huge variation and maximum value indicate that there were days where use

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exceeded 90 minutes and the third quartile indicates that on approximately a quarter of days use exceeded the recommendation.

3.1.4 Pattern of play across the day. Determining whether participants are adhering to the recommended pattern of three 20 minutes sessions a day is not so straightforward. The major difficulty is deciding when a session has started or finished. In order to reach a criterion for an inter session interval, the data for individual participants are being examined. A sample is presented below from one participant to illustrate the varied patterns of use. Figure 9 represents the pattern of play from five consecutive days for participant 9, each line represents one day from 09.00 hours to 23.00 hours. For each hour, whether any use occurred in each of the four 15 minute periods is indicated by a solid filled cell. So for example, on the first of the five days, participant 9 used the equipment at some time between 12.15 and 12.30; 12.30 and 12.45; 12.45 and 13.00 and between 13.00 and 13.15. They then went several hours before recommencing use sometime between 21.15 and 21.30.

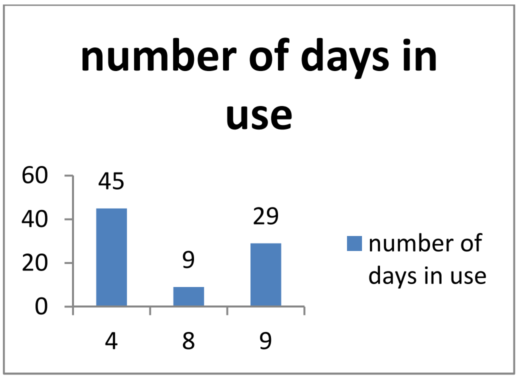

Figure 7. *Total number of days on which the equipment was used by the three example participants.*

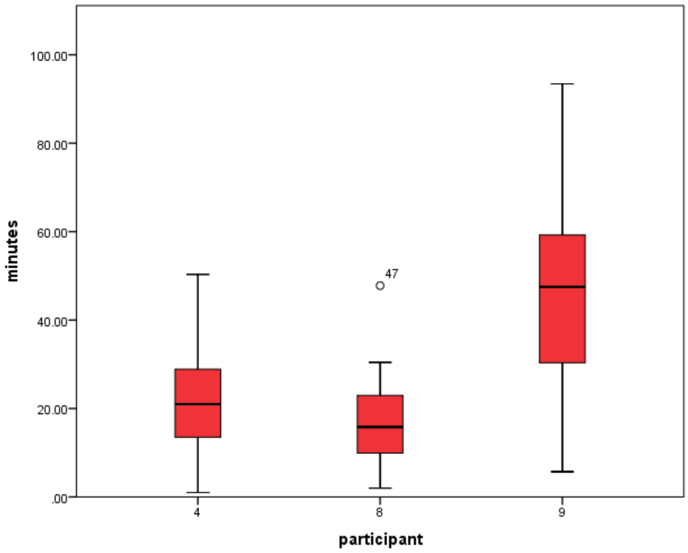

Figure 8. *Daily duration of use in minutes on days that equipment was in use. For explanation see text.*

3.2 Qualitative Data

Analysis of observations from members of the research team making home visits and from interviews with the participants identified several explanations for the low level of use of the equipment as well as aspects that encouraged them to play.

3.2.1 Barriers to use.

- Difficulties with the physical environment eg unable to find location to minimise infra red interference.
- Equipment outages. P4 reported on a few occasions that these made her want to throw it out of the window. Although participants had our phone number they did not always contact us.

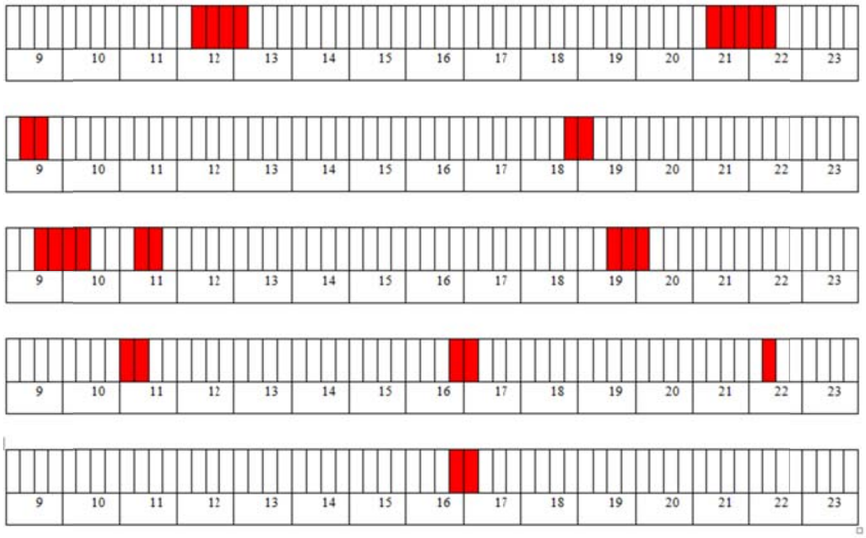

Figure 9. *Pattern of play for a five day period for one participant. For explanation see text.*

- Being dependent on someone to help with equipment. P4 could not change the batteries in the wiimote on her own and get it back in the stand.
- Other health problems eg flu prevent participants from using the equipment. Many people recovering from stroke experience periods of disabling fatigue that require periods of rest throughout the day
- Competing commitments such as looking after children and grandchildren: "And what time the family came, if the family came just when I had started it – I had to then leave it" (P4) , visitors: "Sometimes somebody will come and stop you" (P9) and more passive pastimes: "I admit it depended what was on the telly" (P4). P4 thought 30 minutes a day was practical
- Getting back to pre stroke life especially once mobile (part time working, holidays, driving, gardening, taking sons to football)

3.2.2 Facilitators of use.

- Flexibility: "Whereas with a computer, you could say four o'clock/five o'clock, if you felt all right, you could do it sort of any time you wanted to. You're not set to a time all the time, which was quite good." (P8)
- Immersion in games "You just forget what – you sort of look at the time and, say it was ten o'clock, you're playing and then the next time you look up you think, crikey, it's half-past eleven, sort of thing." (P8)
- Belief in it its therapeutic nature "Oh yeah, of course, because it helps – well, it helps you a lot in your movement. First and fore, with the position, you know, then you enjoy the games." (P9)

4. DISCUSSION

Performance data collected by the software indicate that the pattern of play is variable and can fall far short of our recommendations. However, our recommendations were not based on hard evidence and were a compromise between results from systematic reviews and what we thought would be practical for participants to achieve and not too demotivating. We also wanted to discourage participants from prolonged use to avoid fatigue or the development of side effects (Bonis, 2007) before we could visit to check on whether they were continuing to use the equipment correctly. As a dose response relationship has been shown for practice and recovery (Kwakkel et al, 2004) any increase in activity is beneficial. Additionally, as highlighted by one of the participants, this intervention does allow the flexibility Clay & Hopps (2003) recommended to more appropriately fit into the lifestyles and limitations of patients and their families. Interestingly, whereas some thought the recommended time was fine, others thought it was too much. Additionally, the participant with the lowest use thought he had reached the recommendations, whereas data indicated this was not the case.

This approach to increasing exposure to rehabilitation will not suit every patient who is trying to recover the use of their upper limb following stroke. It has already become clear that a minimum level of movement

and shoulder stability need to be present. However, a technology based approach may not appeal to some people although it would be dangerous to make assumptions based on for example age or computer literacy. Several participants have been over 70 suggesting that age is not necessarily a barrier to computer use. However, if someone has had little experience with computers before their stroke, this skill may be more vulnerable to disruption through the stroke or lack of use. It would also be regrettable if this type of approach was seen as an alternative to the hands on involvement of a therapist rather than supplementing the limited amount of time therapists have available for each patient. As this is a trial, participants are receiving a considerable amount of support from the research team which suggests that as a therapeutic intervention this would still need input from a therapist to be successful.

Due to the operations involved in extracting the data, results for only three participants have been presented. A larger dataset will allow the detection of any patterns and perhaps give some idea of which patients may benefit the most from this type of intervention.

5. CONCLUSIONS

These initial results from three participants indicate just how variable was the use of our home based intervention for rehabilitation of the upper limb and how far short of the recommendations for use two of the participants were. Interviews with participants at the end of the intervention and observations from the research team who had made home visits indicate the barriers to recommended use but also some of the characteristics of the intervention that indicate its potential for improving the opportunity for rehabilitation of the upper limb following stroke.

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Development and validation of tele-health system for stroke rehabilitation

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ABSTRACT

Tele-rehabilitation refers to the use of information and communication technologies to provide rehabilitation services to people in their homes or other environments. The objective of this paper is to present the development, validation and usability testing of a low-cost, markerless full body tracking virtual reality system designed to provide remote rehabilitation of the upper extremity in patients who have had a stroke. The Methods and Results sections present the progress of our work on system development, system validations and a feasibility/usability study. We conclude with a brief summary of the initial stages of an intervention study and a discussion of our findings in the context of the next steps. The validation study demonstrated considerable accuracy for some outcomes (i.e., shoulder "pitch" angle, elbow flexion, trunk forward and side-to-side deviation). In addition positive responses were received from the clients who participated in the feasibility study. We are currently at the process of improving the accuracy of the system as well as conducting a randomized clinical trial to assess the effectiveness of the system to improve upper extremity function post-stroke.

1. INTRODUCTION

Tele-rehabilitation refers to the use of information and communication technologies to provide rehabilitation services to people in their homes or other environments (Burdea et al., 2000). The goal is to improve patient access to care by providing therapy beyond the physical walls of a traditional healthcare facility, thus expanding continuity of care to persons with disabling conditions. The need for evolving the delivery of rehabilitation services and incorporating aspects of self-care and remote monitoring is important in light of the shift in global demographics to an older population and the increasing prevalence of chronic health conditions (Bowling, 2007). Tele-rehabilitation holds significant potential to meet this need and to provide services that are more accessible to more people, while having the ability to offer a more affordable and available care. Moreover, research in neuroscience and especially brain plasticity emphasizes the need for intense treatment and rehabilitation following the acute phase and continuing when the person returns home (Winstein et al., 1999).

The recent development of advanced sensor and remote monitoring technologies has enabled an increasing number of tele-rehabilitation applications to be deployed in the home (e.g., Deutsch et al., 2007; Kairy et al., 2009; Bendizen et al., 2009; Durfee et al., 2009; Golomb et al., 2009; McCue et al., 2010; Mountain et al., 2010). While early telecare projects looked to provide basic follow-up services and caregiver support, later work developed and deployed systems to provide home-based exercise monitoring, diet and medication compliance tracking, robotic-based treatment, and other more dynamic interventions. The advent of low-cost, markerless full body tracking technologies (Microsoft, 2011) has given impetus to continued development and evaluation of robust systems for home use. Research is currently focusing on development of games suitable for use by adults and the elderly with physical and cognitive impairment

(Lange et al., 2009) and on validation of virtual marker identification using customized and commercial tools (Schönauer et al., 2011; Suma et al., 2011; Lange et al., 2011).

The objective of this paper is to present the development, validation and usability testing of a low-cost, markerless full body tracking virtual reality system designed to provide remote rehabilitation of the upper extremity in patients who have had a stroke. The Methods and Results sections present the progress of our work on system development, system validations and a feasibility/usability study. We conclude with a brief summary of the initial stages of an intervention study and a discussion of our findings in the context of the next steps.

2. DESCRIPTION OF GERTNER TELE-MOTION-REHAB SYSTEM

The Gertner Tele-Motion-Rehab system has been designed to provide a home-based tele-rehabilitation program to improve the motor and functional status of people who have neurological dysfunction such as stroke. The set-up includes interaction between the remote client (currently in an on-site lab that simulates the person's home) and the central, hospital-based clinician. The central system includes a unit to support all software to monitor the activity of the remote client and facilities for electronic data storage of intervention outcomes. We use a 3D video capture camera based system (Kinect camera and Microsoft Kinect Software Developer's Kit (SDK)) in which the client's gesture motions control the action of the games. As illustrated schematically in Fig. 1, the system is configured to ensure that it will be a viable online (one-to-one) or asynchronous (one clinician-to-multiple clients) alternative for the rehabilitation of motor and cognitive impairment in patients with neurological dysfunction.

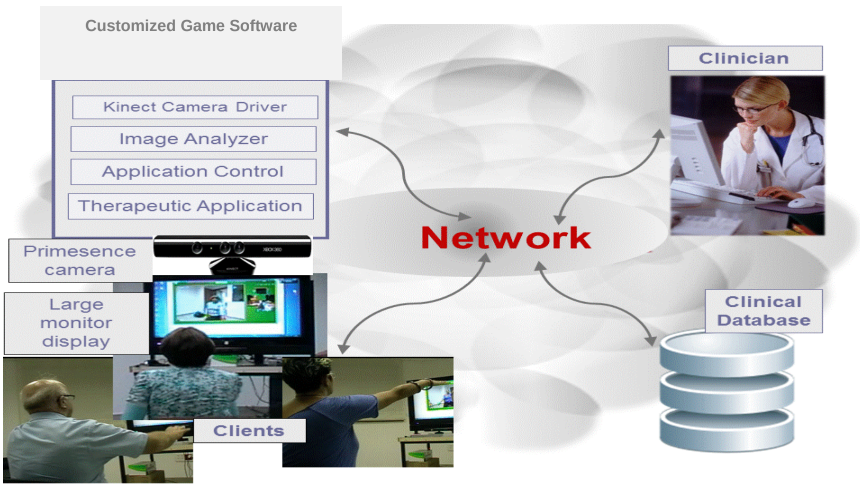

Figure 1. *Schematic illustration of the Tele-Motion-Rehab system as configured for remote, online interaction between client and clinician and/or offline monitoring by the clinician of one or more clients.*

2.1 Design principles of Gertner Tele-Motion-Rehab system.

The software was designed to include both assessment and game-like functional intervention activities. The following design principles were incorporated.

- *Control over level of difficulty.* The level of difficulty is adjusted to the client's abilities (motor and cognitive) to provide just the right challenge of activities/tasks.
- *Knowledge of results.* On-going feedback of game results are provided online to the client as the game progresses and as summary scores at the end of each game. (Details of these scores are provided below in Table 1) These results are also stored off-line for ongoing review by the clinician and retrieval for the client in subsequent sessions.
- *Knowledge of performance.* Ongoing feedback of the quality of movements of the upper limbs as well as compensatory movements of the trunk are provided online (details of this feedback are provided in the next section). This feedback is controlled by a clinician at the evaluation phase in order to match the extent of feedback given to the client's abilities.

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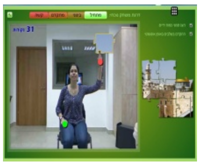
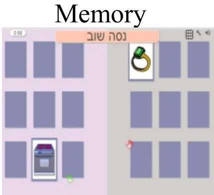
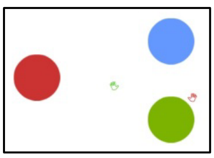
2.2 Evaluation Software

A full kinematic evaluation program was created in order to assess the client's range of motion of the shoulder (flexion and abduction) and elbow (flexion) as well as the magnitude of compensations that occurred while making these movements (shoulder elevation, elbow flexion and trunk lateral and anterior-posterior motion). These data are saved and used to establish the parameters for all games and tasks; when necessary (e.g., the client was fatigued on a given day), the parameters may be adjusted remotely by the clinician. However, they only reset for the games and tasks following a subsequent running of the evaluation program. The re-evaluation program is rerun after a series of four intervention sessions.

Table 1. *Description of five Tele-Motion-Rehab games and tasks developed to date.*

			Level of Difficulty	
Game/Task	Description	Scoring	Motor	Cognitive
Puzzle 	Client reaches to touch puzzle pieces as they appear on the screen. Pieces are automatically placed in correct location when touched. Level of difficulty is changed by pieces appearing at more distant shoulder Range of Motion and by successively requiring that client dwell on one or two pieces (not just touch them).	Time to complete each puzzle.	Simple	Simple
Memory 	Classic 'memory' game in in which cards on each side of the board are exposed until a match is found. Client selects cards by touching them. Level of difficulty is changed by changing display height and successively displaying more card pairs (4-16).	Time to complete game. Number of card selections to complete game.	Simple to difficult	Simple to moderate
Pizza/Hamburger 	Client responds to fast-food orders (pizza or hamburgers) from customers in accordance with a displayed menu. Selection of food items is by touch. The level of difficulty may be adjusted by changing the shelf height, by number of customers and by setting time to complete the meal to be longer. The completed meal is dragged to the customer.	Number of satisfied customers. Time to complete meals.	Moderate	Moderate
Arrows 	Client successively touches colored arrows causes them to move in the indicated direction until they reach "home". Moves have to be strategically planned such that an arrow of one color is used to move an arrow of the other color when necessary since arrows may not be moved backwards.	Number of moves used to complete game. Time to complete game.	Moderate to difficult	Moderate to complex
Tasks 	A series of tasks of increasing cognitive difficulty are solved by touching the indicated images in accordance with instructions (e.g., touch the blue circle first, then the green circle and then the red circle; touch the glasses of wine in order from most full to least full).	Highest level of difficulty achieved with least number of repetitions.	Moderate to difficult	Moderate to Complex

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2.3 Customized games

To date, five Tele-Motion-Rehab games/tasks have been developed. As shown in Table 1, they differ in the type of motion required by the client as well as in their level of motor and cognitive difficulty. For all games several output files are generated and stored for subsequent analysis and review; these include raw kinematic marker data of movements, the parameters used to run the games for each client at each session and the variables describing the game scores.

A screenshot of the Hamburger short order cook task, as an example of one of the games, is shown in Fig. 2. The client plays the role of a short order cook, using gestures to select buns, burgers, tomatoes and ketchup in accordance with the customer's menu selection (shown on the right side of the screen). Both motor and cognitive requirements may be adjusted by changing, for example, the number of the items in the menu, the location of the food items (raising or lowering the shelves), preparation time and number of customers to be served. Note that a silhouette displaying the 3D location of client's head, trunk and shoulders is displayed on the lower right part of the screen; the silhouette's color and slant directly show the client's body position. In addition, visual and auditory messages are given when the client makes compensatory movements beyond a preset tolerance.

Figure 2. *Screenshot showing the Hamburger short order cook task. The client's order is specified in the conversation balloon and the ingredients are listed to the right of the screen. The top shelf is adjustable to make selections harder or easier.*

3. SYSTEM VALIDATION

Demonstration of the accuracy and validity of any low-cost video capture rehabilitation system is essential if it is to be used to provide independent performance (kinematic) feedback to clients. We conducted an extensive series of tests over the past two years at the CAREN™ Virtual Reality Lab, the Laboratory for Human Performance, at the Rehabilitation Center, Sheba Medical Center, Israel. The Vicon optokinetic system (www.vicon.com), consisting of 12 Vicon infra-red cameras and having a resolution of 2 mega pixels was used. Forty-one passive markers were placed on anatomical landmarks (Vicon Full Body protocol), and sampled at a frequency rate of 120 Hz. A healthy male, aged 42, was seated on a stool, and repeated each of the designated movements three times consecutively. A set of 21 movements, each repeated three times, replicating those required to operate the Tele-Motion-Rehab system, was used for each capture session. These movements included, for example, pure shoulder flexion, shoulder abduction and elbow flexion, followed by the same movements but with a concurrent compensation movement (e.g., shoulder elevation, elbow flexion, trunk lateral deviation).

For the purpose of this analysis, and subsequent use in the Tele-Motion-Rehab system, pure shoulder flexion is described as rotation around the x axis, or "pitch". If the movement is not a pure flexion movement, i.e., it includes some shoulder abduction, then the description of the movement is "ɵ" degrees of "pitch" with "ϕ" degrees of "yaw" (rotation around the y axis). The axes of rotation relative to the body are shown in Fig. 3. Outcome measures were computed from marker data (Vicon) and virtual marker data (Kinect), using custom-written Matlab programs (Math-works, Inc., Natick, MA, USA). A 95% limits of agreement method was used to evaluate differences between measurements, corrected for repeated measurements (Bland & Altman, 1986). In Table 2, 95% limits of agreement for each outcome measure and

the mean standard deviation of the three repetitions of each movement are reported. Note that movements where shoulder "pitch" exceeds 115 degrees were removed from the calculation of shoulder elevation due to difficulty in identifying shoulder position (4 out of 21 movements were removed). Note also that negative values of the Bias measure indicate an undershoot of movement as identified via Kinect as compared to Vicon and a positive value denotes an overshoot.

Table 2. *95% limits of agreement for each outcome measure and the mean standard deviation of the three repetitions of each movement.*

	Bias (mean difference between measurements)	Limits of agreement (mean ± 1.96 SD)	SD between repetitions - Vicon	SD between repetitions - Kinect
Shoulder elevation (cm)	-1.25	[-5.23 2.74]	0.56±0.36	1.03±1.10
Trunk flexion/extension (cm)	-0.29	[-2.48 1.91]	1.06±0.79	0.98±0.75
Trunk side flexion (cm)	-0.68	[-3.48 2.12]	0.93±1.14	1.02±0.78
Pitch ROM (deg)	12.54	[2.23 22.85]	2.81±1.56	2.98±1.43
Yaw ROM (deg)	-1.06	[-33.29 31.17]	8.39±4.52	9.13±4.74
Elbow flexion ROM (deg)	-1.79	[-16.20 12.62]	2.95±2.19	4.65±4.31

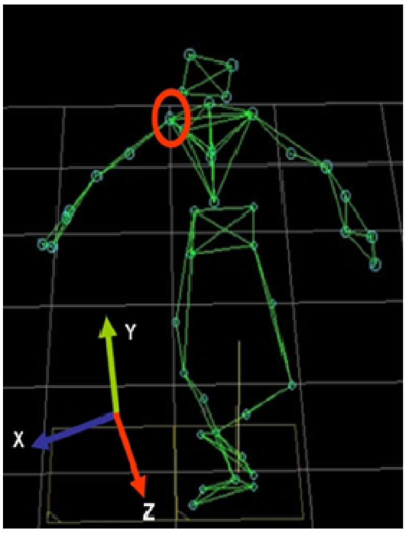

Figure 3. S*ubject model from Vicon marker set showing* x-y-z *axes of rotation relative to body.*

Kinect outcome data contain a small systematic bias for shoulder elevation, trunk flexion/extension and trunk lateral flexion ROM. For shoulder elevation, this bias may increase when shoulder elevation is larger. In all three cases, 95% of the differences are expects to lie under 4cm of the mean. The shoulder pitch angle contains a bias (overshoot of shoulder pitch in Kinect), but 95% of differences are expected within 10.3º of the mean. For all measurements, the between-repetitions SD is comparable to that obtained in Vicon (Table 2). In summary, use of these measures can be made while taking into account these limitations. One measure, the shoulder "yaw" angle had larger differences between measures (95% of differences expected within 32.2º of the mean). We also saw that this angle strongly depends on the subject's location in the workspace, due to nonlinearities in the Kinect workspace. This measure is, therefore, not yet accurate enough for independent use in a rehabilitation setting. Increases in the range of recorded movements as well as the addition of more repetitions of each movement should improve the reliability of our calculations.

Figure 4 shows plots of the outcome measures calculated from the Vicon (x-axis) versus the Kinect (y-axis). Each data point represents an average value of ROM values in three repetitions of the same movement. Dashed line represents the identity line. It is evident that the Kinect shoulder "pitch" angle, elbow flexion, trunk side flexion and trunk forward flexion are more accurate than the values for the shoulder "yaw" angle and shoulder elevation.

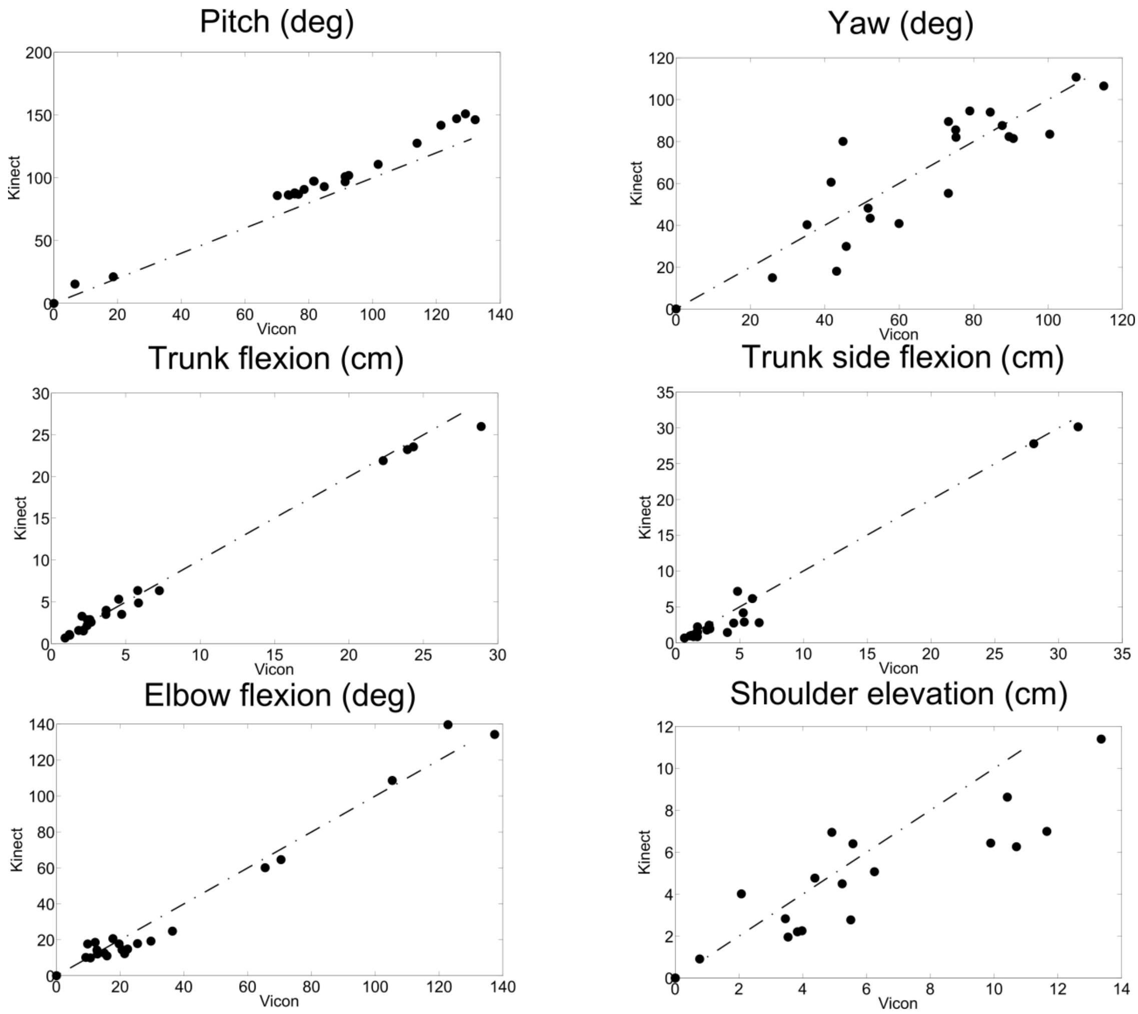

Figure 4: *Outcome measures calculated from Vicon (x-axis) and Kinect (y-axis) data. Each data point represents an average value of ROM values in 3 repetitions of the same movement. Dashed line represents the identity line.*

4. USABILITY STUDY

4.1 Methods

Eight clients with stroke (5 male, 3 female), aged 55-77 years (mean ± SD = 65.6 ± 8.0), participated in the study. Inclusion criteria included mild to moderate impairment of the affected upper extremity. Exclusion criteria included other medical conditions of the central or peripheral nervous system limiting participation in low-intensity exercise training; major receptive aphasia or inability to follow 2-stage commands and screening criteria consistent with dementia (Mini-Mental State Exam (MMSE) score <24); untreated major depression; presence of unilateral spatial neglect as determined by star cancellation (score less than 51); hemianopsia; limb and ideomotor apraxia. Their Fugl-Meyer Assessment for the upper extremity scores ranged from 35-54 (mean ± SD = 46.3 ± 6.5) and their MMSE scores ranged from 25-30 (mean ± SD = 27.6 ± 1.8).

Each subject participated in 6-7 one hour sessions in a hospital-based mock-up "tele" setting. The first sessions were used to assess motor, cognitive and functional abilities using standard clinical tests and then engaged in three sessions requiring upper extremity reaching motions while playing the games as described above. Outcomes included participant responses to the 5-point Short Feedback Questionnaire (SFQ) (Kizony et al., 2006), a usability questionnaire documenting their enjoyment, and perception of success and control while using the system. They also completed the Borg scale (1990) to rate their perceived effort while playing the games, where 6 indicates a minimal effort and 20 indicates a maximal effort. In addition to these subjective ratings, game performance scores were tabulated.

4.2 Results

Feedback from this study was very positive in terms of enjoyment (mean ± SD SFQ item 1 = 4.6 ± 0.52). The mean ± SD Borg scores = 9.9 ± 2.4 indicating a moderate rating of effort. The variability of the performance scores was considerably higher. For example, although shelf height and number of customers (n=5) served during the Hamburger short order cook task was the same for all participants, the time they took to complete it varied from 2.42-6.00 min (mean ± SD = 4.18 ± 1.29).

In the Memory game, the highest successfully completed level varied from a total of 4 pairs of matched cards (1 participant), to 6 pairs of matched cards (6 participants) and to 9 pairs of matched cards (1 participant). Time to complete the game ranged from 2.3-8.9 min (mean ± SD = 3.74 ± 2.19). However, when the number of cards per minute was calculated the variability decreased considerably (range = 1.0-2.6 cards per min; mean ± SD = 1.88 ± 0.62).

These results were used to determine the protocol for the clinical effectiveness study (via a small sample Randomized Control Trial) that we are now commencing and the optimal way to provide feedback when clinician and client are not in face-to-face contact.

5. CONCLUSIONS

The results of this study indicated that the 'Gertner Tele Rehab system' is feasible for use for upper extremity rehabilitation after stroke. The validation study has, to date, demonstrated considerable accuracy for some outcomes (i.e., shoulder "pitch" angle, elbow flexion, trunk forward and side-to-side deviation). The accuracy of other outcomes, namely shoulder "yaw" and should elevation need to be improved before they can be used to provide online clinical feedback. We are currently continuing to improve system accuracy and, in the meantime, use the problematic outcomes with great caution.

Several modifications to the software were made as a result of the feasibility study, and prior to commencement of the ongoing Randomized Control Trial (RCT). For example, small demonstration applications were made to instruct the clients regarding the movements required to control each game. Additional games that include a greater cognitive challenge which makes them more similar to tasks encountered in real life settings were developed. The games were adjusted to better accommodate both motor and cognitive abilities of the clients. Preliminary results from the RCT in which a 12-session tele-intervention is being compared to self-directed home exercises, indicate that the revised system is feasible and enjoyable. These results will be presented at the conference.

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Using a virtual supermarket as a tool for training executive functions in people with mild cognitive impairment

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ABSTRACT

Cognitive and executive functions (EF) intervention programs for people with mild cognitive impairment (MCI) has not been studied enough, especially with the use of virtual reality. The purpose of the current study was to examine the effectiveness of using the Virtual Action Planning – Supermarket (VAP-S) to improve performance of a shopping task and EF among people with MCI. Seven participants with non-amnestic or multi-domain amnestic MCI completed the study protocol which followed an ABA single subject design. The outcome measures included the Multiple Errands Test (MET) to assess EF while performing a shopping task and the WebNeuro to assess EF impairments. Results showed that 4 participants improved their EF as assessed by the WebNeuro and 4 improved their performance of the shopping task in the MET. It seems that in some cases a learning effect occurred which explains why some of the participants did not improve. The results point to the potential of using the VAP-S as an intervention tool for training EF in people with MCI.

1. INTRODUCTION

Mild Cognitive Impairment (MCI) is considered as the early phase of cognitive decline in older adults (Werner and Korczyn, 2008) and incorporates observed clinical heterogeneity, with various subtypes: amnestic (memory impairments) or non-amnestic and either multi-domain (impairment in additional cognitive areas) or single-domain (Winblad et al, 2004). Executive functions (EF), defined as higher-order cognitive functions needed for performing complex tasks (Godefroy, 2003) have been shown to be impaired among persons with MCI (Nelson and O'Connor, 2008) especially in the areas of response inhibition, cognitive flexibility, attentional switching (Traykov et al, 2007), and planning (Zhang et al, 2007).

Intervention approaches for treating cognitive deficits in people with MCI focus mainly on memory disabilities and may include: physical exercise (Erickson and Kramer, 2009), medications (Jelic and Winblad, 2003) and cognitive group therapy (Kurz et al, 2009). There is some evidence for the effectiveness of these interventions, however, the evidence is not strong and the treatments usually did not address executive dysfunction and the impact on performance of Instrumental Activities of Daily Living (IADL).

Virtual Reality (VR) technologies which have been used as an assessment and treatment tool in cognitive and EF rehabilitation (Kizony et al, 2008; Klinger et al, 2010; Kizony, 2011), have advantages in providing an ecological–valid environment for treatment, which is considered to be more useful in EF rehabilitation. These environments may be used to train meta-cognitive strategies to enable a better transfer of skills to real life according to Toglia's dynamic interactional model which is widely used in cognitive rehabilitation (Toglia, 2011).

The Virtual Action Planning- Supermarket (VAP-S) (Marié et al, 2003; Klinger et al, 2004) is a virtual supermarket that was found to be an ecologically valid tool for the assessment of EF in people with Stroke

(Josman et al, 2006), Schizophrenia (Josman et al, 2009), Parkinson Disease (Klinger et al, 2006) and MCI (Werner et al, 2009).

Intervention studies for the treatment of cognition and EF showed some evidence for the use of VR. Rand et al. reported substantial improvements in the Multiple Errands Test (MET) - Hospital Version in 4 post-stroke participants when they received 10 treatment sessions in the Virtual Mall (VMall), a video-capture VR system using a single-subject design (SSD) (Rand et al, 2009). Yip and Man showed that 3 out of 4 participants with Acquired Brain Injury were able to transfer memory skills to a real-world environment after 10 training sessions in environments that simulated the use of public transportation and shopping (Yip and Man, 2009).

Despite the growing evidence of using VR for rehabilitation of EF deficits, the emphasis has been more on the assessment of EF deficits rather than on their treatment benefits (Kizony, 2011), with no studies in persons with MCI.

The objectives of this study were: 1. To examine the effectiveness of using the VAP-S to improve EF in people with MCI and 2. To examine the VAP-S effectiveness in improving performance of a shopping task in real world.

2. METHODS

2.1 Participants

Four women and 3 men who were diagnosed with non-amnestic or multi-domain amnestic (mixed) MCI were included in the study, using a Single Subject Design method. Their ages ranged between 65 and 89 years and all were living at home (See Table 1). Diagnosis of MCI was done by an expert physician using a comprehensive cognitive tests battery.

2.2 Outcome measures

Multiple Errands Test - Simplified Version (MET-SV) (Knight et al, 2002), a validated test for a variety of populations (Alderman et al, 2003) is an assessment designed to examine EFs in a real mall environment. An adapted version of the assessment was formulated for the current study to be used in a large supermarket. The scoring was based on Rand et al., (Rand et al, 2009). The final score of performance in the MET-SV, ranging between 0-133, was determined by the total number of mistakes made by the participant; therefore, the lower the score, the better the performance was.

WebNeuro battery (Brain Resource Company) (Silverstein et al, 2007) is a reliable and valid accessible web-based cognitive test battery that takes 30 minutes to administer. The battery contains subtests in few cognitive domains such as memory, attention, psychomotor functioning and especially executive functions. It includes few Hebrew versions for repeated measures.

Table 1. *Participants' characteristics*

Parti-cipant	Type of MCI	Gender	Age	Family status	Education (years)	Shopping frequency
1	Mixed	M	65	Married	17	Once a week
2	Non amnestic	F	85	Widow	12	Once a week
3	Non amnestic	M	76	Married	8	Few times a week
4	Mixed	F	65	Married	16	Sometimes
5	Mixed	F	69	Married	12	Once a week
6	Mixed	M	89	Widow	36	Once a week
7	Non amnestic	F	74	Married	12	Sometimes

2.3 Intervention tool

The VAP-S Virtual Environment (Klinger et al, 2004) simulates a fully textured, medium-sized supermarket (Fig. 1). Users enter the supermarket behind a cart, as if they are pushing it, and can navigate freely within the VAP-S via the keyboard arrow keys. They experience the environment from a first person perspective. A list of items appears on the screen and the user is asked to shop for those items, go to the cashier, pay and exit the supermarket. Prior to the beginning of this study, the VAP-S was modified by Klinger to enable the use

of the VAP-S as a training tool. The modifications include the ability to grade the level difficulty of the shopping tasks.

Figure 1. *The Virtual Action Planning- Supermarket- VAP-S* (Klinger et al., 2004).

2.4 Procedure

After signing an informed consent form, each subject underwent the following protocol which followed an ABA single subject design (See Fig. 2): Initially, a baseline evaluation with the MET-SV and the WebNeuro battery and after 3-4 weeks a second evaluation (with a different version of the battery) was performed. This was followed by 10 treatment sessions over 5 weeks which were performed by a therapist blinded to the assessments' results. The treatment protocol was tailored to each subject and was based on Toglia's model (Toglia, 2011) focusing on training of meta-cognitive strategies within the VAP-S. After completing the training a third evaluation with another version of the above tests was performed and finally, a fourth evaluation was performed 3-4 weeks after completing the training.

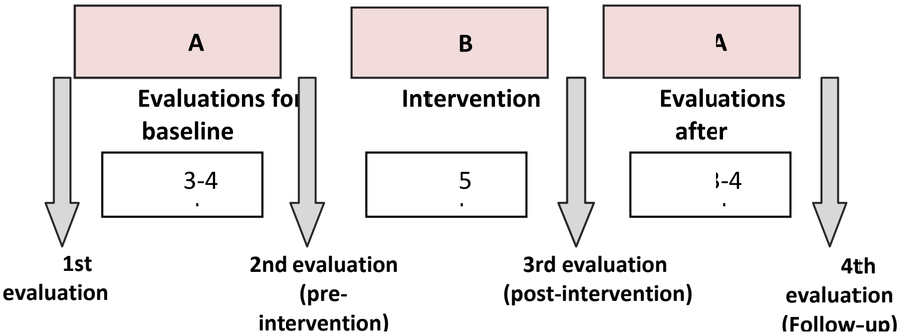

Figure 2. *Illustration of study design.*

3. RESULTS

Data was analyzed descriptively as appropriate in a single subject design. Results showed that 4 subjects improved in their EF as assessed by the WebNeuro (Fig.3) and 4 subjects showed some improvement in their total MET-SV (Fig.4). Two of those showed improvement in both assessments. Median scores of EF as assessed by the WebNeuro increased between the first 3 evaluations and then remain unchanged on the 4th evaluation (See Fig. 5). Similar tendency was seen in the median scores of the Total MET-SV (See Fig. 6)

From a qualitative point of view subjects enjoyed the treatment and compliance was good. In addition four of them indicated that the treatments sessions helped them in improving their strategies during performance of other everyday activities.

4. DISCUSSION AND CONCLUSIONS

The findings of the current study point to the potential of using the VAP-S as an intervention tool within a meta-cognitive model for training of EF in people with MCI. The between and within subjects' variability was high which might point to the heterogeneity of deficits in this population and thus indicate that single subject design method as was used in this study, is the appropriate design for this population.

Four participants showed an improvement in their total scores of the MET-SV suggesting the transfer of strategies trained during the intervention, into a real life situation. This is considered to be an intermediate

transfer according to (Toglia, 2011) since performance in real world was assessed in a supermarket and training was performed in a virtual supermarket. However, it seems that in some participants skills were transferred to other activities as well. For example, this is a quote from one of the participants: “now I’m more organized and I learned various strategies that will help me in the performance of daily activities, not only during shopping, but also while performing other tasks.”

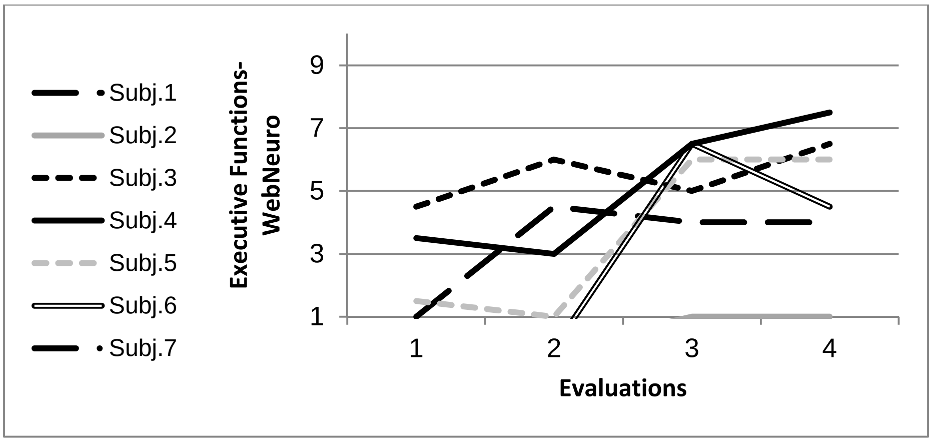

Figure 3. *Results of EF domain from the WebNeuro Battery in 4 evaluations (note that 2 subjects were not able to complete the EF domain of the battery at the first evaluation and one also in the second and one subject was not able to complete this domain in all 4 evaluations).*

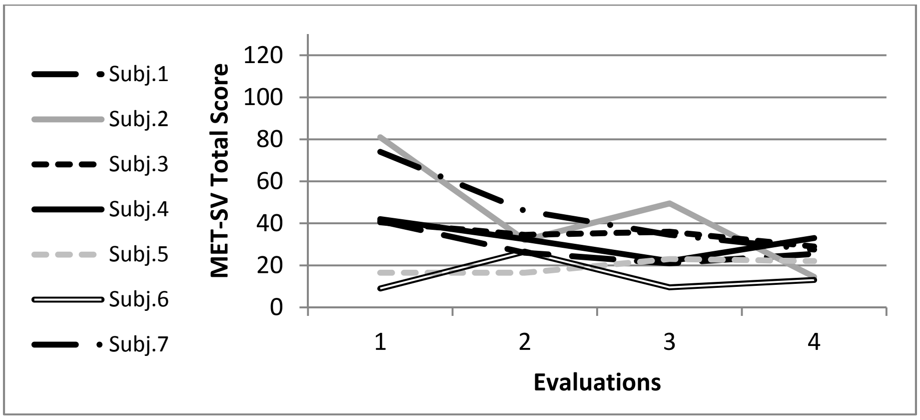

Figure 4. *Total scores of MET-SV in 4 evaluations (low scores indicate better performance).*

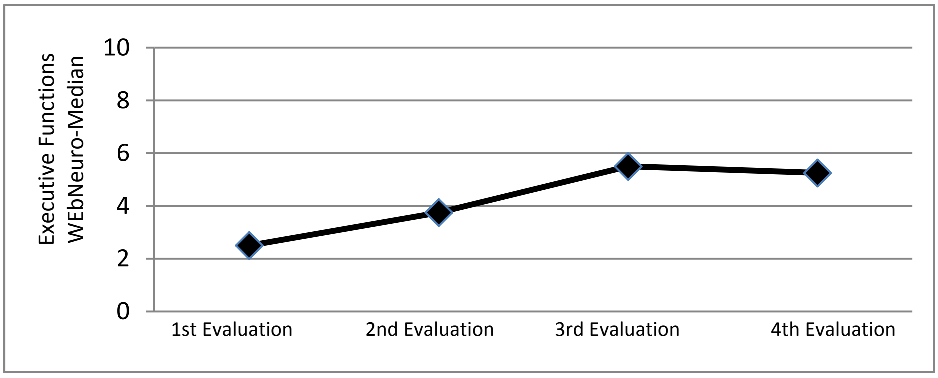

Figure 5. *Medians of EF domain from the WebNeuro Battery in 4 evaluations (n=7).*

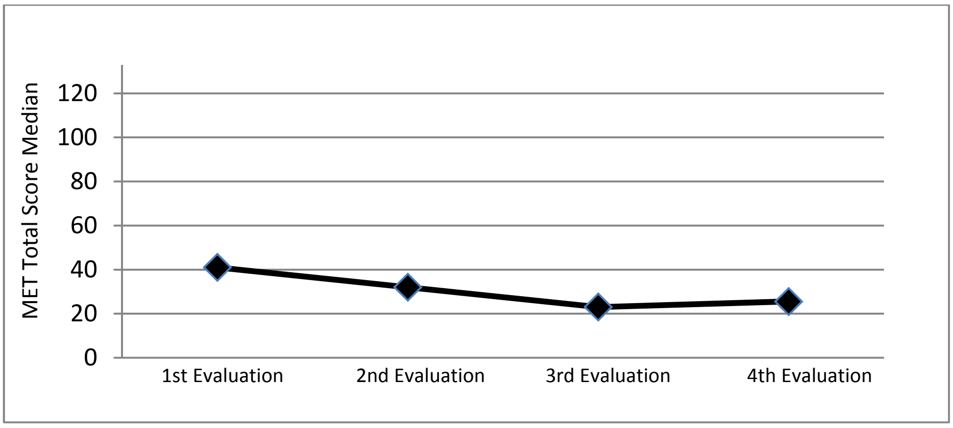

Figure 6. *Medians of MET-SV in 4 evaluations (low scores indicate better performance)(n=7).*

There are few explanations why some of the participants did not show improvement of EF or performance of the shopping task post intervention. Analysis of the results revealed that there was a learning effect from the first evaluation to the second. This can be seen in Figures 5 & 6 in the median scores as well as in the individual participants in Figures 3 & 4. The learning effect might be due to two main reasons; learning of the tasks within the assessments, and familiarity with the task in WebNeuro or with the testing environment (i.e. the supermarket) in the MET.

Rand et al., (Rand et al, 2009) reported an improvement in total scores of the MET post intervention, in all 4 participants in their study. However, the participants were only assessed twice; pre and post intervention, thus learning effect was not controlled. In the current study, when looking only at two evaluations as in Rand et al., study, most participants showed an improvement in the MET (n=7) and the EF domain of the WebNeuro (n=6).

Another explanation why some of the participants did not improve post intervention is their level of awareness to their deficits that might impede transfer of skills to other situations. In addition, emotional state like anxiety or depression might affect the ability to learn and use efficient strategies for daily life activities (Toglia, 2011). These functions were not measured in the current study.

A tendency of decline in performance in the 4th evaluation was observed in the WebNeuro (1 participant) and in the MET-SV (3 participants) and is also apparent in the group's medians. This might be explained by a change in the level of motivation of the participants once the intervention was over and there was nothing to look forward to in the future, in terms of the research.

The limitations of this study are mainly the small sample size and the lack of a control group. In addition, intervention was limited to one VE, a supermarket, which does not reflect the complexity of everyday life.

In conclusion, although the results should be interpret cautiously, the protocol developed in this study using the VAP-S, may help improve EF and shopping task in people with MCI. Further studies should be carried out in a larger sample of participants with MCI as well as other clinical populations.

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Rehabilitation tools along the reality continuum: from mock-up to virtual interactive shopping to a living lab

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ABSTRACT

The purpose of this study was to compare shopping performance using the 4-item test, between three types of environments; a real environment (small, in-hospital “cafeteria”), a store mock-up (physical simulation) and a virtual environment (Virtual Interactive Shopper-VIS), in a post-stroke group compared to a control group. To date, 5 people with stroke and 6 controls participated in the study. Participants performed the original 4-item test (“buy” 4 items) in the VIS and the store mock-up as well as a modified 4-item test (“buy” 4 items with budget constraints) in all three environments. Results were analyzed descriptively and findings to date, indicate that the post-stroke group performed more slowly than the control group. In addition, in both groups, the time to complete the test within the VIS was longer than in the store mock-up and the cafeteria. Performance in the VIS, the store mock-up and the cafeteria were correlated in the post-stroke group. Finally, participants’ responses to their experience in the VIS were positive. The preliminary results of this small sample show that the test within the VIS is complex and realistic and may be used to assess and train the higher cognitive abilities required for shopping.

1. INTRODUCTION

Shopping is one of the most significant and meaningful instrumental activities of daily living (IADL), yet only a small percentage of the post-stroke population continues to engage in this and other complex life tasks (Hartman-Maeir, et al., 2007; Rand et al, 2007). In addition, although research into the effects of aging on various life habits has grown substantially in recent years, there is insufficient knowledge on how older adults perform in complex life situations, partly due to technical limitations of measurement tools. Mitchell’s (http://livinglabs.mit.edu/) concept of “Living Labs as a research paradigm for sensing, prototyping, validating and refining complex solutions in multiple and evolving real life contexts” is a potential solution to this difficulty, and may be considered the definitive realization of participatory design to identify true user behaviour (Følstad, 2008). One of the goals of a “Living Lab” is to assess and train behaviour in complex settings, and to find ways to overcome environmental barriers in order to enable inclusive participation by all people, including post-stroke and elderly populations.

Computer simulations of complex settings enable the analysis of performance from various viewpoints in a precise way, as well as the evaluation of various solutions to accomplish specific tasks (e.g. using a specific cognitive strategy) before their implementation in a real environment. In addition, complex tasks can be validated and tested in people with disabilities interacting with the simulations, for future use in a Living Lab. The two main options for simulating a real-life activity are to use a virtual environment (Kizony et al., 2008) or a physical mock-up environment.

A number of virtual supermarkets, running on desktop computers, were found to be valid for assessment of the higher cognitive abilities (i.e., executive functions (EF)) needed for shopping. (Castelnuovo et al., 2003;Josman et al., 2008; Klinger et al., 2004; Lee et al., 2003). Rand et al. (2005) developed the Virtual

Mall (VMall), a virtual supermarket that runs on a video-capture VR system which has the advantage of integrating and assessing both motor and cognitive aspects of task performance, thus making it similar to real life activities. Rand et al. (2009) demonstrated the ecological validity of the VMall as an assessment of EF during a shopping task in elderly and post-stroke subjects. The main disadvantages of the VMall are the somewhat complex set-up needed for its operation (e.g., a "green screen") and the limited options of adding additional stores or budget management to increase task complexity (i.e. cognitive and motor demands of the task). More recently, the Virtual Interactive Shopper (VIS) was developed on the SeeMe video capture VR system (Brown et al., 2011). It enables the creation of a shopping mall composed of different stores that can be changed and adapted according to the habits and preferences of the shopper, including the need to handle a budget.

Performance of complex IADL tasks within VEs and comparison of performance on the continuum from a virtual supermarket, to a store mock-up and a real shopping task has not yet been studied. This will enable the examination of the relationships between shopping performance in these three environments which complement one another for the purposes of rehabilitation assessment and treatment. It will also help in understanding the use of VEs to train skills in the clinical setting and whether these skills transfer to real world life situations.

The objectives of this study were: 1) to compare shopping behavior with the original and modified 4-item tests between persons post-stroke and healthy controls (in terms of time to complete the tests and number of errors). 2) to compare the performance in the 4- item test in three different environments: a real environment (small, in-hospital "cafeteria"), a store mock-up (physical simulation), and a virtual environment (VIS); and 3) to determine the participants' responses to the shopping experiences in the VIS in terms of their enjoyment and perception of its similarity to real life.

2. METHODS

2.1 Participants

Six healthy adults (five women, one man), aged 56-77 years (mean ± SD = 63.5 ± 9.3) and five people (two women, three men) who had a stroke, aged 65-82 years (74.8 ± 6.6), participated in this study. All participants with stroke were inpatients at a Geriatric Rehabilitation Center. Time since stroke ranged from 1 to 7.5 months. Their mean Functional Independence Measure score was 88.4 (SD = 19.5) (maximum score is 126) and the mean of their Mini Mental State Exam scores was 26.4 (SD = 4.8).

2.2 Instruments

The environments tested were:

(1) Virtual Interactive Shopper (VIS), a virtual environment of a 3-store mall that operates on a video-capture VR system, SeeMe (Fig. 1) (http://www.virtual-reality-rehabilitation.com/products/seeme). It is possible to assess and train the use of money with a virtual wallet.

(2) A store mock-up that was created in the Geriatric Rehabilitation Hospital at the Sheba Medical Centre (Fig. 2).

(3) Cafeteria in the Geriatric Rehabilitation center at the Sheba Medical Centre that served as the location of shopping in a real setting (Fig. 3).

Outcomes were measured during performance of two versions of the 4-item test: 1. the original 4-item test (Rand et al., 2007) in which the subject is instructed to "buy" 4 items (VIS: 1 kg of sugar, 500 ml bottle of soda, 1 kg package of rice and 500 ml bottle of orange juice) within a virtual supermarket while the list is visible during the test. The test was also performed in the mock-up using a different list of items (1 liter carton of milk, 1 liter bottle of chocolate milk, 500 ml package of salt, 1 kg package of flour). This test was not administered in the cafeteria since the use of money is not required. Rand et al. (2007) reported significant differences in performance of this test between healthy adults and people with stroke, within the VMall; 2. A modified 4-item test which was developed for the current study in which the subject is instructed to "buy" 4 items. In the modified version, subjects have budget constraints so that they must decide between buying cheaper or more expensive items. In this scenario, the shopping list is also visible to the subject during the test. To avoid learning effects three different versions were created and used in all three environments; the VIS (package of pasta, package of yellow cheese, loaf of bread, container of yoghurt), the store mock-up (carton of milk, package of white cheese, can of corn, package of chicken soup mix) and the cafeteria (items were chosen according to availability and prices in the cafeteria).

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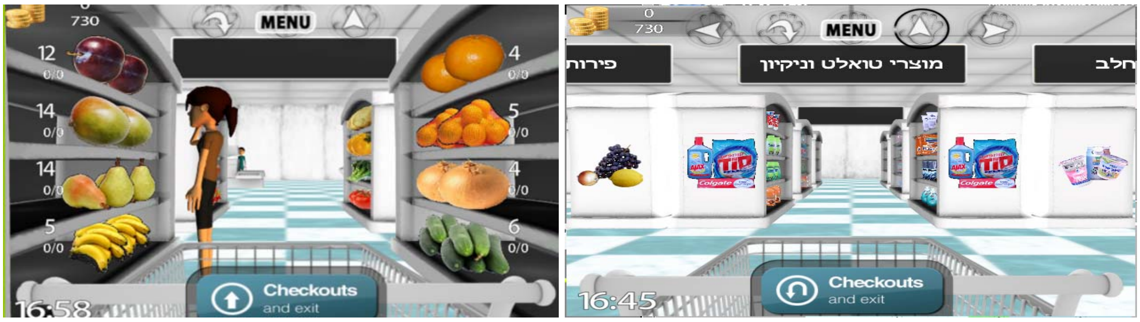

Figure 1. *Two screenshots of the Virtual Interactive Shopper (VIS).*

Figure 2. *Two views of the store mock-up.*

Figure 3. *Sheba Medical Center cafeteria.*

In both versions of the 4-item tests, the time to complete the test (from the moment the subject said that he was ready to start until he said that he had finished) and the number of errors (e.g., buying the wrong item or not buying an item on the list) were recorded. In the modified version, an additional type of error was recorded concerning the budget handling, i.e., spending more than the specified amount. In addition, in the VIS, the locations visited within the VE by the subject were recorded by the software.

The Short Feedback Questionnaire (SFQ) (Kizony et al., 2006) was used to record participants' responses to the shopping experiences in the VIS in terms of their enjoyment and perception of its similarity to real life. The questionnaire is composed of six items that assesses the participant's (1) feeling of enjoyment, (2) sense of being in the environment, (3) success, (4) control, (5) perception of the environment as being realistic and (6) whether the feedback from the computer was understandable. Responses to all questions are rated on a 5-point scale (1 – not at all and 5 – very much). An additional question inquires whether the participants felt any discomfort during the experience.

2.3 Procedure

The study was approved by the Ethics committee of the Sheba Medical Center, Tel Hashomer, Israel, and each subject signed an informed consent before participating. The order of testing environments was

randomized between the subjects. In the VIS, two practice trials were given before the 4-item tests were performed. In the first practice trial, the subject was asked to buy a basketball; the researcher explained how to navigate within the VIS and then gave the subject an opportunity to navigate to the toy store and buy the item. The purpose of the second practice was to enable the subject to become familiar with the virtual supermarket; the subject was asked to enter the supermarket and navigate in the main shopping area in order to scan the various aisles. Thereafter the subject was asked to buy toilet paper which was located in an aisle that was not part of either of the 4-item tests in the study protocol. Subjects completed the SFQ after they performed both 4-item tests within the VIS. The original and the modified 4-item tests was administered within the mock-up store after a short explanation about the structure of this model. The modified 4-item test was administered in the cafeteria.

2.4 Data analysis

Descriptive statistics of performance in all outcome measures will be presented in this preliminary study due to the small sample size.

3. RESULTS

The time to complete both versions of the 4-item tests in all environments, for two groups, is presented in Fig. 4. The time to complete the original and modified 4-item tests within the VIS was longer than the time to complete a similar test within the physical store mock-up for both groups. The time to complete the test in the cafeteria was similar to the time it took to complete the test in the mock-up store. The control group completed the tests in a shorter time. The least difference between the groups was noticed in the real environment.

In Fig. 5, performance of the individuals on each test within the VIS and the mock-up store as well as in the cafeteria are presented. The relationship between the time taken to complete the test within the VIS and the mock-up store or the cafeteria tended to be stronger for the stroke group especially in the modified 4-item test (Fig. 5B & D).

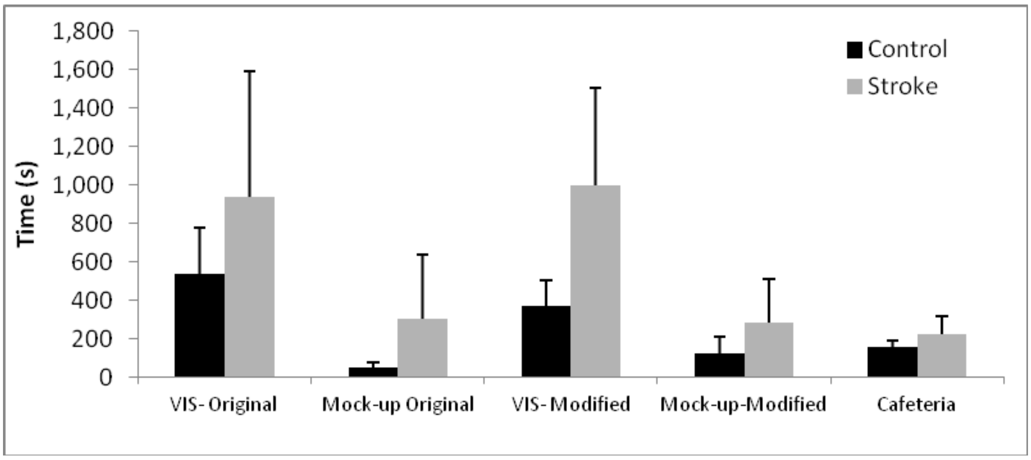

Figure 4. *Mean (+SD) time to complete the two versions of the 4-item test (original and modified) in the environments.*

Analyzing the number of errors in each group showed that, in the original 4-item test in the VIS, all participants made at least one error. However, the total number of errors for the post-stroke group was 12 (n=5) and for the control group was 8 (n=6). Only one subject from the post-stroke group made an error in the same test in the mock-up store. In the modified version of the test in the VIS, one subject from the post-stroke group and two subjects from the control group made errors (total for stroke=4 and control= 2). In the same test in the mock-up store, three subjects from the post-stroke group and two from the control group made errors (total for stroke=5 and control= 3). In the cafeteria, one subject from the post-stroke group and two from the control group made errors (total for stroke=1 and control= 4).

Fig. 6 illustrates the locations visited by one of one subjects with stroke (aged 74 years) and one control (aged 77 years) within the virtual supermarket during the adapted 4-item test. It can be seen that the subject with stroke wandered around the virtual supermarket more than the control subject.

Participants' (n=11) subjective perceptions of their experience within the VIS were positive, as reported in the SFQ; they enjoyed the task (mean = 4.2 ± 0.9) and reported that it appeared to be realistic (4.2 ± 0.9).

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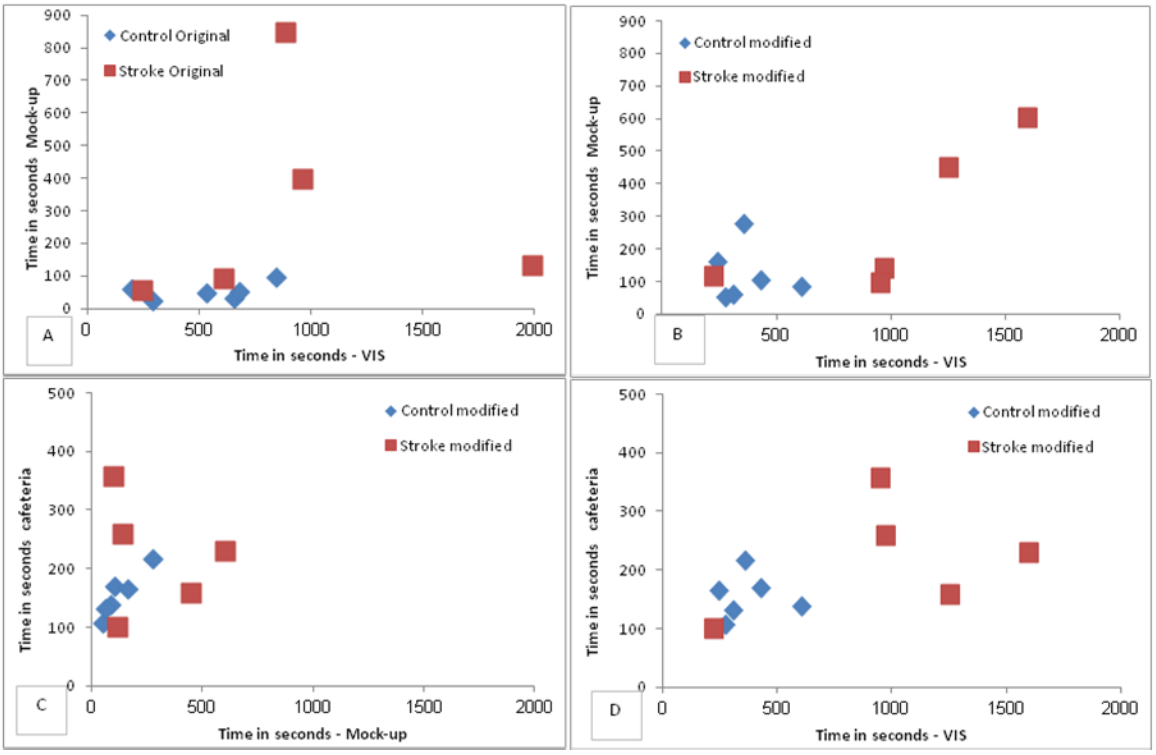

Figure 5. *Relationships between the times to complete each test in the different environments; A. Original test in the VIS and Mock-up; B. Modified test in the VIS and Mock-up; C. Modified test in the Cafeteria and Mock-up; D. Modified test in the VIS and Cafeteria*

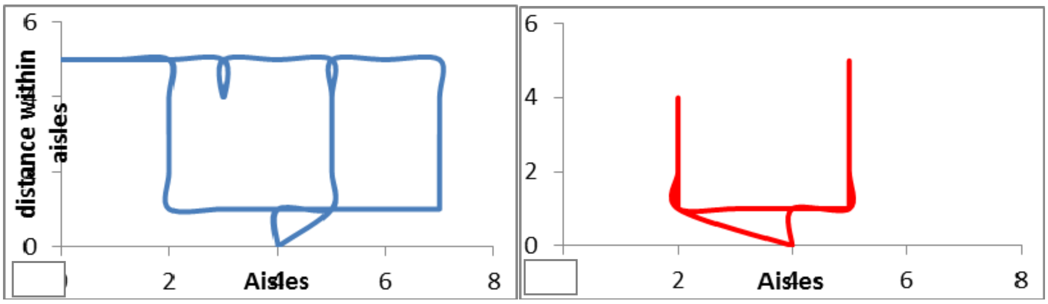

Figure 6. *Locations visited within the virtual supermarket of A. a subject post-stroke and B. a control subject*

4. DISCUSSION AND CONCLUSION

The preliminary results of this small sample show that the task within the VIS is complex and realistic and may be used to assess and train the higher cognitive abilities needed for shopping.

Time to complete the original 4-item test within the VIS was longer than the time reported by Rand et al. (2007) for both groups. This may be explained by the differences in VR systems used for the two studies (as mentioned in the introduction).

Due to the small sample, to date, no statistical tests were performed but there was a tendency for the post-stroke group to perform more slowly than the control group in all environments and that this difference was more remarkable in the simulations (virtual and physical) than in the cafeteria (real). In addition, the time to complete the tests, in both groups, was longer in the VIS than in the Cafeteria or the store mock-up. These results may indicate that the test within the VIS might have been more difficult than the tests in the store mock-up or a the cafeteria that were used in this study. However, in the post-stroke group it appears that the times to complete the modified 4-item test in the VIS were related with both the store mock-up as well as the cafeteria (Fig. 5B & 5D). This, although needs to be cautiously interpreted due to the small sample, may indicate that similar skills are needed to complete the tests in these environments.

The analysis of the number of errors revealed that, overall, only a few errors were made by each group. This is currently being further examined in terms of the types of errors and the ability of participants to self-correct.

One of the main advantages of using VR for evaluating performance of complex tasks is the outcome measures provided by the software. The illustration of the locations visited by the subject within the VIS presented in Fig. 6, is an example for the difference in strategies used by the participants to complete the test within this environment. The person with stroke appeared to use a less efficient strategy to locate and "buy" the items by wandering around the virtual supermarket and entering unnecessary aisles. If carried out in real world, such a strategy (or, in fact, perhaps the absence of any strategy) would require greater effort (i.e., walk longer distances) in order to perform shopping activities.

Finally, similar to previous studies using VEs (e.g., Rand et al., 2007; 2009) the positive responses of the participants indicate that the VIS may be used in rehabilitation as a training tool for improving real life participation.

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So much technology, so little time: factors affecting use of computer-based brain training games for cognitive rehabilitation following stroke

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ABSTRACT

Rehabilitation following stroke typically focuses on regaining use of the affected lower and upper limbs. Impairment of cognitive processes, however, is predictive of rehabilitation outcomes. Stroke survivors and their caregivers report difficulty finding time to practice gait and upper limb training at home due to the time demands of routine activities of daily living (ADL), leaving little time for cognitive retraining. Cognitive activities have become more readily accessible to the home user through web-based games that engage brain functions often disrupted by stroke. With neuropsychological testing, it is possible to "prescribe" brain training that targets the specific cognitive functions disrupted by an individual's acquired brain injury. We asked if computer-based braining training were made available in-home at no cost, would stroke survivors complete the training? Five stroke survivors participated, none completed the recommended 40 training sessions. Interviews with participants and caregivers reveal barriers to training including physical and cognitive limitations, as well as time and fatigue management. Training also showed effects on ADLs and mood.

1. INTRODUCTION

Rehabilitation following stroke routinely takes a bottom up approach, with primary focus placed on gait retraining (Putnam et al, 2006), followed by upper limb rehabilitation, and speech and language therapy. Impairment of higher order cognitive processes (comprehension, judgment, short-term verbal memory, abstract reasoning) however, predicts length of inpatient stay as well as number and frequency of referrals for outpatient and home therapies (Galski et al, 1993). Stroke patients and their caregivers frequently report difficulty finding time to practice gait and upper limb training in the home environment due to the increased time demands create by physical disability. Completing routine activities of daily living (ADL) with impaired upper and lower extremities can take much of the day. When appointments for outpatient therapy and medical follow-up are added to the day, patients and caregivers report little or no available time for self-initiated therapies, such as cognitive rehabilitation, despite the importance of cognitive processes in physical recovery.

Cognitive activities have become more readily available to the home user through the availability of web based brain training games that engage brain functions often disrupted by stroke. Computer based brain training is available for improving memory, attention, speed of information processing, mental flexibility and problem solving. Research has demonstrated that brain training can combat cognitive decline associated with the normal course of aging. In addition to improving performance on training tasks, the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study demonstrated training generalized to measures of real world function (Ball et al, 2002), and benefits were sustained for as much as five years after training time (Willis et al, 2006).

With appropriate neuropsychological testing, it is possible to "prescribe" brain training games that target thespecific cognitive functions disrupted by an individual's acquired brain injury. We initially invited community based stroke patients involved in outpatient neuro rehabilitation to participate in an interventional study that required adherence to a training schedule. Feedback from patients and their caregivers revealed little likelihood of compliance due to the time demands of ADLs and outpatient therapies, consistent with Clay and Hopps (2003) findings of non-adherence to rigid regimens. The focus of this project was then shifted to examine factors affecting use of computer based brain training when the goal was defined (40

sessions of training, 15-30 minutes each) and the parameters regarding how the goal would be achieved were not. Lumosity (www.lumosity.com), a web based suite of brain training games grounded in neuroscience research, was selected for this single case series study. Lumos Labs, creator of Lumosity Games, offers a research portal which makes it possible to capture frequency, duration, and outcome of use at no cost to the participant. The brain training games target cognitive domains of function that are most often affected by stroke including memory, attention, processing speed, decision-making ability, and mental flexibility. Additionally, the Lumosity games are novel and engaging exercises in which the difficulty level continuously adapts to each individual's progress.

2. METHOD

2.1 Design

Participants were recruited from the clinical neuropsychology practice of Bonnie Connor, PhD. Each participant was asked to: 1) train on the Lumosity Basic Course (www.lumosity.com) suite of games as frequently as possible until 40 sessions were completed, 2) notice what factors interfered with training and 3) what factors made training easier. Participants agreed to complete a semi-structured interview when training was completed.

2.2 Participants

5 participants with right hemisphere stroke, ranging in age from age 63 to 73 years, participated in the study with the following inclusion criteria:

- Complete pre-training neuropsychological evaluation.
- Have access to a computer and the internet.
- Have adequate visual ability to view a computer screen.
- Have adequate motor ability to operate computer keys and use a mouse.
- Be willing to respond to semi-structured interview questions.

Table 1. *Characteristics of Participants.*

Participant	Sex	Age	Education (years)	Handed	Stroke (month/year)	Stroke Location	Depressed (GDS)
NB	F	63	16	R	12/2010	R-MCA	Mild
EB	M	73	19	R	12/2011	R-MCA	No
BF	M	66	14	L	05/2010 12/2008	R- Hemorrhagic	Mild
PP	M	67	14	R	11/2011	R-MCA	No
JW	F	65	12	R	06/2011	R-MCA	Mild

2.3 Neuropsychological Measures

Neuropsychological testing included measures of global cognition, verbal and visual memory, visuospatial skills, language functioning, and executive abilities including attention, processing speed, working memory and abstract reasoning. All measures were adapted from the University of California Medical Center, Memory and Aging Center's Bedside Screen, and used their age and education corrected normative database. Global cognition was measured with the Mini-Mental Status Exam (MMSE). The maximum score is 30 points. Scores above 25 are considered within normal limits (WNL) for the age range of these participants. Verbal memory following a 15-minute delay was measured with a 9-item list-learning task repeated over 4 learning trials. Visual memory was measured using a modified complex figure that was initially copied and, following a 15-minute delay, freely recalled and recognized in the presence of foils. Speed was measured with a phonemic fluency task in which as many words as possible beginning with a letter of the alphabet are generated in 1 minute, under constrained conditions (no proper names, no repeating a word by changing the ending). Attention to detail when copying a modified complex figure was used to measure attention. Problem solving was measured by design fluency, under constrained conditions (5 rows of 7 boxes per row, each box

containing 5 dots in the same location with the instruction to make a different design in each box by connecting dots with 4 straight line. Lines may intersect, not all dots have to be used).

Table 2. *Pre-Training Neuropsychological Testing Percentile Scores.*

Participant	**Global Cognition (MMSE)**	**Memory (Verbal Delayed)**	**Memory (Visual Delayed Recall %; Recognized Y/N)**	**Speed (word fluency)**	**Attention (Complex Figure Copy)**	**Flexibility (Trail Making Modified)**	**Problem Solving (Design Fluency)**
NB	WNL	30%	< 0.1% - N	21%	10%	< 0.1%	1%
EB	WNL	25%	19% - Y	18%	34%	50%	4%
BF	WNL	2%	< 0.1% - N	8%	< 0.1%	< 0.1%	0.1%
PP	WNL	30%	19% - Y	27%	0.4%	37%	50%
JW	WNL	30%	3% - N	53%	95%	32%	2%

2.4 Games

Lumosity, developed by Lumos Labs (www.lumosity.com), offers a set of web-based brain training games to improve cognitive function. The training is based on the volume of literature showing that behavior leads to structural and functional changes in the brain associated with specific task demands. Research has demonstrated that brain training can combat the cognitive decline associated with the normal course of aging. In addition to improving performance on training tasks, the Advanced Cognitive Training for Independent and Vital Elderly (ACTIVE) study demonstrated training generalized to measures of real world function (Ball et al, 2002), and benefits were sustained for as much as five years after training time (Willis et al, 2006). The Lumosity brain training programs focus on critical characteristics of effectiveness including: 1) targeting brain functions that will lead to the maximum benefit for users in daily life which involves transfer of improvement in the games to performance of real world tasks; 2) adaptivity based on setting training at a level that is challenging without being discouraging, and that adjusts task difficulty in response to individual user performance on a moment-to-moment dynamic basis, within task and across sessions; 3) novelty since working in new ways that are not over-learned is critical for driving nervous system remodeling; 4) engagement to keep the brain in an engaged and rewarded state, which makes it more receptive to learning and change, with rewards teaching the brain mechanism to process information more effectively; and 5) completeness by targeting a range of cognitive functions including processing speed, attention, memory, flexibility, and problem solving. Processing speed training uses spatial orientation and information processing tasks; attention training includes visual field and visual focus tasks, memory involves spatial recall, face-name recall (Figure 1), and working memory tasks focused on symbols, rhyming words, and visual-spatial pattern location and memory; flexibility includes task switching, response inhibition, verbal fluency, and planning (mazes); and problem solving uses basic arithmetic functions (addition, subtraction, multiplication, and division), logical reasoning (Figure 2), and quantitative reasoning (Hardy & Scanlon, 2009).

Participants were provided with a unique user name and password for access to the Lumosity web site (www.lumosity.com) research portal. Participants, and their caregivers (where appropriate), were given visual and verbal instructions describing how to access the program. Each participant was instructed to play the games as often as possible to complete 40 sessions.

2.5 Semi-Structured Interview Questions

Participants and caregivers were asked to respond to the following questions: 1) what problems did you experience during the study, 2) what was difficult about the training, 3) what was easy about the training, 4) were there problems with the software either with a) setting it up or b) the games themselves, 5) what were the best times of day to play, 6) on the days you did not play the games, why not, 7) have any activities of daily living (ADL) improved as a result of playing the games, and 8) would you purchase a Lumosity www.lumosity.com) subscription to continue training once the research protocol is completed.

2.6 Analysis

Pre/post training quantitative analysis was not possible as no participant completed the training. Thematic analysis (Braun & Clarke, 2006) was used to analyze the semi-structured interview data. Telephone interviews were conducted with all 5 participants, and 2 of their caregivers. Interview responses were transcribed, coded relative to the research questions, and analyzed using a theoretical thematic analysis.

Figure 1. *Familiar Faces. This game involves the user working as a server in a seaside restaurant. Each visitor has a name and places an order. The server must remember the orders and customer's names to earn a large tip. The game exercises associative memory for verbal and visual information. As performance on the task improves, more characters and more complicated orders are presented. The user must remember names within session and from previous sessions. This screen shot appears courtesy of* [Hardy & Scanlon, 2009].

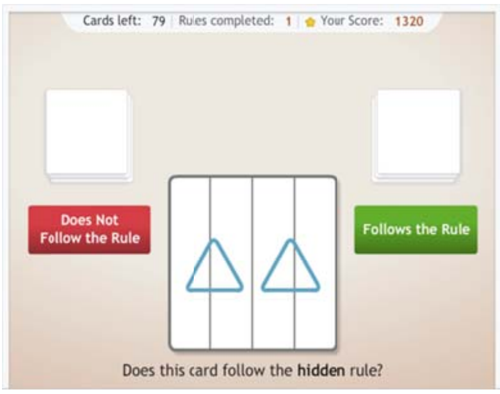

Figure 2. *By the Rules***.** *Users must identify the hidden rule in a dynamic card game by indicating with each card which rule the card follows. In the example screen shot, the card might follow the rule if the rule were "blue," "triangle," "number 2,""vertical lines," or "solid border." If the user indicates the card follows a rule and it does not, then it must be another rule. However, if the user indicates it follows one of the aforementioned rules, and is correct, there are still 5 possible rules. Only through multiple tries is it possible to determine the rule. This game exercises mental flexibility and working memory, while using inductive and deductive reasoning. The user is challenged to formulate hypotheses about the current rule, and dynamically update their hypotheses as new information becomes available***.** *This screen shot appears courtesy of* [Hardy & Scanlon, 2009].

3. RESULTS

Semi-structured interviews were completed with each of the 5 participants, and 2 of their caregivers, between 28 and 29 June 2012. Access to the Lumosity (www.lumosity.com) research portal revealed no participant had completed 40 sessions as of 29 June 2012. Two participants (NB, EB) had Lumosity subscriptions, which they had used for several sessions prior to the research project. Total sessions completed by participants: NB – 13, EB – 0, BF – 14, PP – 14, JW – 1.

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3.1 Barriers to Use

Three themes emerged when examining overall problems with the training: physical limitations, cognitive limitations, and time and fatigue management.

3.1.1 Physical limitations including hemiplegia, hemianopsia, and color blindness contributed to problems with training. Some of the games require using the up, down, left, and right arrow keys, while other games required use of the alpha keyboard to type words. Four of the five participants have left hemiplegia resulting in only one hand being usable for manipulating the keyboard. JW said, "I can only use the right hand." NB said, "The biggest frustration is not using both hands for typing." PP said, "I only have one hand to type with. Anything involving the keyboard is difficult because of 'hunt and peck'" One of the participants (BF) is left-handed, has left hemiplegia, and also has visual field deficits as a result of hemianopsia. He is unable to play any of the games without the assistance of his caregiver. One participant (PP) is color-blind and found it "really frustrating to get the color games."

3.1.2 Cognitive limitations contributed to game play in several ways.

- *Log in.* Each of the five participants had difficulty accessing the online games without assistance. Lack of computer skills was a frequent comment, including not knowing how to login. "I'm technologically challenged. I would need Carrie (wife) to find the password and access the account" (EB). JW said, "I couldn't remember how to login. I get a little hyperventilating on the computer. I'm not so good on computers. I have performance anxiety." She had completed only one session at the time of the interview. She required her husband's assistance to login and did not want to bother either him or the researcher for assistance. During the telephone interview, we attempted to login. It was evident from this experience that the computer was not allowing her to go directly to the Lumosity web site. She was also getting numerous prompts that she did not understand how to respond to, including passwords kept in the 'keychain' that were inaccurate due to typing errors on her part.
- *Comprehension.* One participant (EB) misunderstood the training instructions to mean he was to continue playing games using his subscription rather than the research portal. Comprehension and information processing also contributed to other difficulties. BF is both physically and cognitively unable to access the internet on the home computer, start the program, or respond to some tasks without assistance. BF's caregiver (wife) said he had trouble "getting the directions for what he is supposed to do, and then following through fast enough to do the game."
- *Lack of awareness of deficits.* Scores on the depression inventory revealed each of the participants was either not depressed at all, or only mildly depressed despite significant physical and cognitive limitations. One participant (NB) stated, "I don't feel I have any problems" despite her caregiver (husband) indicating she was not able to login without assistance.

3.1.3 Time and fatigue management, especially fatigue management, was a consistent theme with each participant. Most participants said they preferred to play in the afternoon because "the morning routine interrupts" (NB). BF's caregiver (wife) said, "if we have activities away from the house, when we get home he is tired and can't sit down at the computer. After attending to the daily routine of blood pressure, pills, and hygiene it takes 15 minutes to get out of the house and into the car (due BF's mobility difficulties). A one hour appointment takes up the whole day." EB said he was trying to do the program when 'fresh.' Ideally he wanted to do it "first thing in the morning and I have a lot to do then," and even later in the day "I'm still tired." On days when participants did not train the consistent response related to too little time and fatigue. JW said, "I get busy with life." EB said he was "busy doing a bunch of other things. I'm on 4 boards (non-profit organizations)." PP said, "Probably because I've had a lot of other things going on, circumstances out of my control." BF's wife said 4 days a week he cannot do the training due to outside activities including 2 days a week of physical therapy. "Outside activities use up (BF's) energy reserves, he can't do it." NB's husband said, "Some days she's very tired."

3.1.4 Problems with software. Problems with the games were related to the physical and cognitive limitations of the participants. "Not being able to get out of a game that is too difficult" was a problem for BF. His hemianopsia and left visuospatial neglect were also a problem with screen navigation. After scanning the whole screen, BF's wife said he "disregards what he saw on the left." Visual scanning was a problem for other participants, as well. EB said, "the 'bird game' was OK until they added the distractions." Most participants stated word games that required using the entire keyboard presented problems. "Word games don't allow enough time to 'hunt and peck'" (BF's wife). Cognitive problems with the word games related to individual limitations with generativity. JW said, "If I could run and get my dictionary" and EB said, "I had trouble coming up with more words." Navigating quickly enough with the mouse was also a problem. EB

reported problems with "hand-eye coordination." PP said, "When I move the cursor to 'how to play' I would get a bunch of screens."

3.2 Facilitators of Use

- *Short duration of training sessions.* Each training session lasts 15-30 minutes. The feature most frequently cited as a facilitator of use was this short duration of sessions. PP found "the short time to get in and out of a program" made it possible for him to play more than once a day. "If I have a spare moment I sit down and do it." BF's wife said, "The length of the program is a good length."
- *Problem Solving.* Most participants found the basic arithmetic problems easy. EB said, "I could do the problems" and JW said, "I liked those." Others found the logical reasoning tasks to be "user friendly" (BF's wife), "it is a concept he can work with."
- *Game Playing Experience.* Experience with the games also made doing them easier. PP said, "Once I started getting interested it got a lot easier. A lot was very interesting. I'm discovering speed bumps in my head."

3.3 Improvement in Activities of Daily Living

Participants generally found the training to improve memory, speed of information processing, problem solving, and visual scanning. Mood was also affected by training. Caregivers reported modest improvements in daily functioning.

- *Memory.* NB reported she could "remember words better. I used to loose names of plants, now not so much." EB reported the facial recognition has "gotten me more in tune with paying attention to names, which I've always been terrible at."
- *Problem Solving.* PP noted in his daily life, "When I see I'm making a mistake, I don't continue doing it. I developed strategies to offset my personal difficulties."
- *Visual Scanning.* NB said "when I do 'Bird Watching' a lot I can notice things in my peripheral vision very quickly." While her husband observed that changes he has noticed are "small," he said, "she is reading a lot better." In the past she would "pass over chapters" and now she does not.
- *Mood.* Two of the 3 participants who have completed more than 2 training sessions found training to improve their mood. NB's husband said when she is "down, depressed or angry and does Lumosity she feels better." NB reported the "success factor improves my mood." PP also noticed improved mood. JW, who has completed 1 session said, "I don't know what made me feel sharper, quicker in my brain. I like doing it." In contrast, BF, who has profound physical, visual, and cognitive deficits, finds most of the games frustrating because he is unable to do them, and is unable to quit out of games that are too difficult.

3.4 Would you buy a Subscription?

The 2 participants who already have subscriptions would continue their subscriptions. The remaining 3 participants cited financial limitations to purchasing a subscription. PP said, "If money was not an issue I'd do it." JW and BF's wife cited fixed incomes with expenses going up and income going down to be limiting factors. BF's wife said, "We would have to commit to a 3-year subscription to make it affordable. A 1-year subscription is too expensive."

4. DISCUSSION

Qualitative data suggest, when left to decide when and how often to play brain training games to improve cognitive functioning, stroke survivors have difficulty finding the time, and are often physically and cognitively challenged by task demands beginning with the login process. In the absence of a trainer or 'coach,' participants had difficulty initiating training, and persisting with training in the presence of physical and cognitive challenges. Once training is initiated and pursued, however, the process becomes easier and the benefits are more apparent. Despite Clay and Hopps (2003) findings of non-adherence to rigid regimens, participants in this study found it difficult to establish routines of their own that would facilitate a consistent, predictable, reliable training regimen. As a consequence, no participant completed the recommended 40 sessions of training. It is notable that the one participant who overcame the computer problem of frequently getting "multiple screens" during training, also wanted to train whenever possible once he developed some facility with the program. Participants in this study will be followed through completion of 40 sessions of training, after which post-training measures of neuropsychological functioning, self-reported competency, as well as semi-structured interview results will be obtained and reported.

For commercial products, such as Lumosity, to be viable for patients with physical and cognitive limitations, it will be important for game features to include: 1) allowing adequate time for visual scanning of the video display and responding to stimuli in the presence of problems with visual scanning and visuospatial neglect, 2) adequate time for navigating the keyboard one-handed, and 3) the ability to quit out of games that are beyond the participant's abilities. Additionally, establishing a pricing structure that takes into account the financial limitations of older adults on fixed incomes will be important.

5. CONCLUSIONS

The initial results from the 5 participants in this study reveal the difficulties stroke survivors experience on a day to day basis with managing the fundamental activities of daily living, before supplemental activities can be added to their schedule. While each of the participants was interested in brain training games, designing a product that is commercially viable for a wide ranging audience is difficult. The task demands of training suitable for an older adult who has experienced a stroke leading to physical and cognitive deficits are very different from training suitable for a young adult seeking to maximize their cognitive functioning. The availability of web based training for cognitive recovery following brain injury offers tremendous potential for in-home, on-demand rehabilitation.

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3D augmented reality applied to the treatment of neuropathic pain

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ABSTRACT

Neuropathic pain is characterized by a permanent or recurrent background pain including stinging, tingling, allodynia, burning, shock or stabbing sensations. It significantly alters the patient quality of life. Such painful conditions are observed in the case of phantom limb pain (PLP) and complex regional pain syndrome (CRPS), and are difficult to treat effectively. Recent studies show the crucial role of the central nervous system in these pathologies and suggest a link to the plasticity of the latter. Mirror visual feedback (MVF) is often used in case of amputation, CRPS or stroke to restore normal cortical organization and to lower pain intensity. We have conceived an augmented reality (AR) system that applies the principle of MVF without requiring the use of a physical mirror. The system strengthens the patient's immersion and concentration by using realistic, natural looking 3D images that are acquired, processed and displayed in 3D, in real time. Our system is based on standard inexpensive hardware and is easy to install and to use. This makes it perfectly suitable for use in a therapist's practice or at home. The preliminary results of clinical tests show that the system can significantly reduce the pain, after only a few training sessions.

1. INTRODUCTION

Neuropathic pain is defined by the International Association for the Study of Pain (IASP) as "pain initiated or caused by a primary lesion or dysfunction in the nervous system" (IASP, 1994). Many patients with neuropathic pain present persistent or paroxysmal pain. This stimulus-independent pain can be lancinating, burning and also characterized by symptoms like stinging, tingling, allodynia, burning, shock or stabbing sensations… In this context phantom limb pain (PLP) and complex regional pain syndrome (CRPS) are considered as neuropathic pain, and most recommendations are recommendations for neuropathic pain syndromes.

Phantom sensations are the non-painful or painful sensations experienced in the body part that no longer exists. The prevalence of PLP is more common among upper limb amputees than lower limb amputees (Subedi and Grossberg, 2011). The most commonly description of pain is tingling, throbbing, piercing and pins or needles sensations.

CRPS is a weakening, painful condition in a limb, associated with sensory, motor, autonomic, skin and bone abnormalities. It appears commonly after injury to that limb. Limb signs such as sweating, swelling and color changes usually reduce with time. Unfortunately pain persists. The aetiology of CRPS is unknown. Characteristically, there is interplay between peripheral and central pathophysiologies.

Cortical reorganization is one reason evoked for the cause of PLP and CRPS. During reorganization, the cortical areas representing the amputated extremity are taken over by the neighboring representational zones in both primary somatosensory and the motor cortex. The extent of cortical reorganization has been found to be directly related to the degree of pain and the size of the deafferentiated region. In CRPS, several studies have indicated that cortical reorganization plays a role in the persistence of the symptoms.

Recent advances in neuroscience and cognitive science have opened up new possibilities to treat this kind of pathology. A relatively new way to decrease pain and to improve function for the patients with upper limb

disabilities is to use the visual feedback provided by mirror therapy. Mirror therapy or mirror visual feedback (MVF) was first reported by Ramachandran and Rogers-Ramachandran (1996) and is suggested to help PLP patients by resolving the visual proprioceptive dissociation in the brain.

The principle of MVF (Ramachandran and Altschuler, 2009) is simple: using a mirror, the patient observes virtual movements of his affected limb as a mirror reflection of the movements of the opposite healthy limb. Working this way allows one to restore consistency between the motor intention and the visual feedback, which causes cortical reorganization, resulting in a persistent decrease in pain.

Given the positive effect of visual feedback through a mirror in case of phantom pain, and the fact that it gives the illusion that the amputated arm is “alive” again, mirror therapy usage has been extended to other pathologies, like CRPS and stroke with variable success.

In this paper, we present a prototype system that combines 3D Virtual Reality (VR) technologies and the principles of MVF, and how we apply it to the treatment of neuropathic pain.

The usage of VR for the treatment of pain is not recent. Moseley (2007) combined a mirror for the upper part of the body and a projector for the lower part in order to simulate a virtual walking for paraplegic patients. He observed effective reduction of the neuropathic pain endured by the patients. In pilot studies from Murray et al. (2006) and Sato et al. (2010), VR is applied to MVF for treating CRPS or PLP. Their respective setups track the motion of the hand using a data glove and movements of the arm or leg using sensors attached to the limbs of the patients. The problem with this approach is that it requires the patient to be equipped with a quite complex tracking system, making the whole system cumbersome and difficult to use at home. Also, the reconstructed image shown to the patient is a pure virtual arm that hardly looks like his real arm.

2. MATERIAL AND METHODS

The main objective we had in mind, when we designed our system, was to increase as much as possible the immersion of the patient. By immersion, we mean the illusion he has that what he sees is the reality. To achieve this, we decided not to work with an approximate representation of the patient in the form of an avatar, but with real 3D images of the patient shown on a 3D display. In that sense, our approach could be parented to an augmented reality (AR) system, according to the definition given by Azuma et al. (2001).

2.1 Description of the setup

The patient wears 3D glasses and looks at himself on a 3D screen. A 3D camera captures his movements in real-time and the system augments this 3D reality in two ways : (1) by performing some specific image processing, like lateral flipping or applying a virtual mirror as we will explain later, and (2) by adding to the scene some virtual objects of different shapes and sizes with which the patient may interact.

The 3D camera is the Kinect™ from Microsoft. It produces depth and color images that are synchronized and calibrated, at a rather good resolution (640x480 pixels) and with a good frame rate (30 frame per second), all of that for a rather low cost. For the display, we use the 3D Vision Kit™ from nVidia which offers active stereovision, and a 120 Hz display screen.

2.2 Construction of the 3D Images

To construct the 3D images, we use the depth image that is delivered by the Kinect and we transform it to a set of points (also called vertices) in the 3D space, or point cloud in the literature, by using the calibration parameters of the camera. After that, the system meshes these vertices together based on their relative positions in the depth image (Figure 1, top left) and applies them a texture by using the color image coming from the Kinect (Figure 1, top right).

A straightforward method to construct a mesh from a point cloud consists in finding the nearest neighbors for each vertex and connecting them to the vertex with triangles. In a general case, the search for the nearest neighbors is very costly in computation time, and even if there exists algorithms optimized for this task, the computation time is not compatible with our requirement of real-time display. Fortunately, in the current case we can simplify the problem since we have at our disposal the depth image coming from the camera. This image is organized in pixels along two dimensions, each pixel corresponding to a vertex in the point cloud. We will use this 2D pixel organization to pre-determine the neighborhood relationships between the vertices of our point cloud. Figure 2 illustrates how neighbor vertices are connected together based on the 2D organization of their corresponding pixels. This technique works well for triangles that connect vertices belonging to the same surface and that are close to each other in terms of Euclidean distance. But some pixels

that are direct neighbors on the depth image may in reality be located in 3D space at very different depth values, producing distorted (elongated) triangles in the mesh (see red triangles on Figure 1, bottom left). This is typically the case for pixels that correspond to the edge of an object. After identification and removal of these bad triangles we obtain a nice and clean 3D mesh (Figure 1, bottom right).

This whole process has to be repeated for each depth image that comes from the camera, 30 times per second. In reality, the computation has to be even faster than that because in order to display a 3D image on the screen with stereovision, we have to generate two different views of it, one for each eye. To be able to sustain such a frame rate, we let this process run on the highly parallel architecture of the graphics card. We pre-load a static mesh organization that matches the organization of the pixels in the 2D image. When the graphics pipeline is ready to render a triangle of the mesh, it calls a specific geometry shader. This shader determines whether the current triangle may be rendered based on two simple criteria: (1) it requires that each vertex of the triangle has a depth value contained in a given range, (2) it also requires that the maximum depth difference between the three vertices of the triangle is smaller than a certain threshold (in our case 3 cm). If these criteria are not met, the geometry shader discards the triangle and it is not rendered. The geometry shader acts thus as a filter on the triangles.

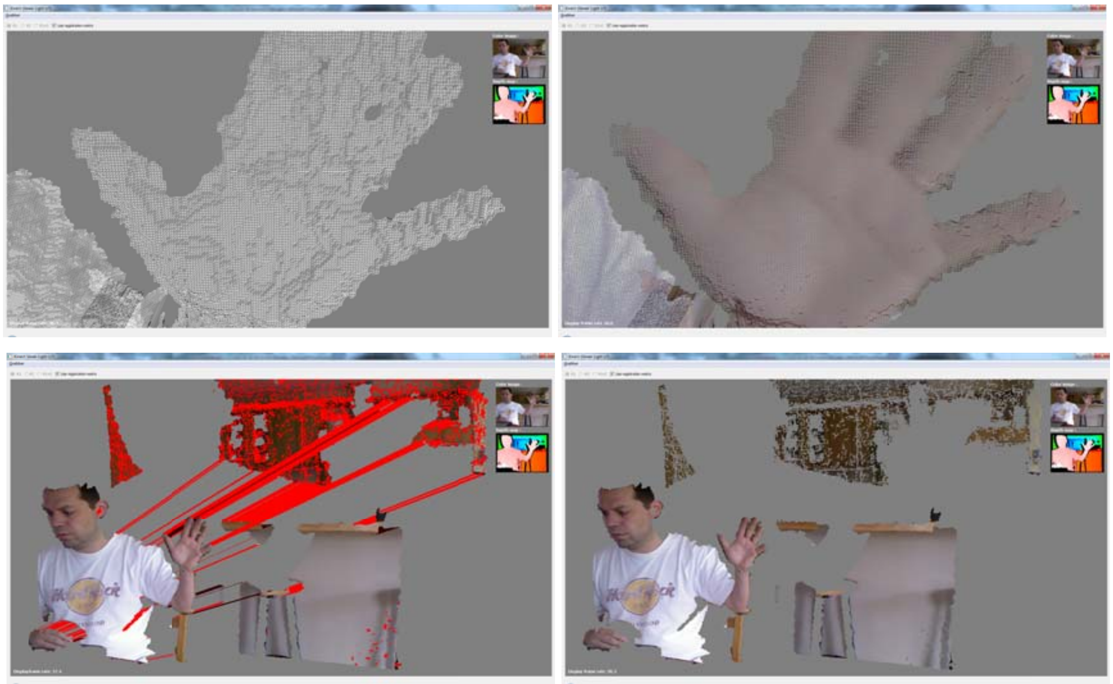

Figure 1. *Successive steps involved in the construction of the textured 3D mesh starting from the point cloud coming from the Kinect.*

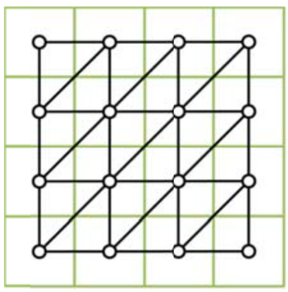

Figure 2. *The connectivity between the vertices of the mesh is defined based on the 2D organization of the pixels (green boxes) in the depth image. It results in a set of triangles (shown in black).*

Since we work with one camera, we can only reconstruct the portion of the volume that is visible with the camera, that is to say the frontal part of the volume of the patient's body. This may give the impression that we lack a part of the image. We are also limited by the resolution of the depth image produced by the Kinect (640x480 pixels). Despite these limitations, the quality of the generated images is quite good and is certainly

sufficient for the use we make of it (Figure 3). Moreover, the fact that the patient watches the images in 3D strengthens the perception of quality and realism.

Figure 3. *Sample frame to illustrate the quality of the generated images.*

2.3 Application of the mirror effect

By convention, the 3D frame of reference of our system is the one of the camera. The origin is at its focal point and the Z axis corresponds to the focal axis. The X and Y axes correspond respectively to the horizontal and vertical axes of the camera.

The virtual mirror is defined by a plane which is always positioned vertically and perpendicularly to the focal plane of the camera, that is to say parallel to the YZ plane. The only degree of freedom of the mirror is a lateral displacement along the X axis. The system also manages a parameter that determines which side of the mirror is the reflecting one. The application of the mirror is very straightforward: all the triangles of the mesh that are located on the non-reflective side of the mirror are removed and all those that are on the reflective side are duplicated symmetrically with respect to the mirror's plane (see Figure 4).

At this stage, there still remains an issue to tackle: the mirror effect works well for the trunk and the arms showing quite convincing results. But the result on the face is rather disgraceful (see Figure 5). To solve this, we have defined a “safe zone” around the head of the patient where the effect of the mirror is not applied (see Figure 4, middle and right images).

This part of the algorithm is also implemented as a specific geometry shader.

Figure 4. *Application of a virtual mirror to a 3D image. The left part shows the original image. In the middle part we see the virtual mirror in pink and the safe zone in green. The right part shows how the 3D mesh that is on the right side of the mirror is duplicated symmetrically to the left side, except inside the safe zone.*

2.4 Automatic positioning of the mirror

Even if the patient sits still in front of the screen and tries to move only his arm, we observe small movements of the other parts of his body like the head or the trunk. The visual side effect of these parasite movements is that the patient seems to go partially in and out of the mirror. To get rid of this, we have implemented a visual tracking of the patient’s head position at each frame. We use this position to automatically place the mirror and the safe zone at the center of mass of the head’s image.

Figure 5. *Effect of the "safe zone": on the left image, the safe zone is not activated, on the right image, it is activated.*

To track the head, we proceed as follows: we seek the highest pixel inside a central vertical strip of the depth image. This pixel corresponds approximately to the top of the head. We compute the projection of this pixel in 3D space and we outline a parallelepipedic volume centered on this point in X and Z and placed below it in Y. This volume is dimensioned to be certain to contain any patient's head and possibly the beginning of the shoulders, even if the upper pixel is not perfectly centered with regards to the head. We then calculate the centroid of all the vertices included in this volume, and their minimum and maximum coordinates. The X coordinate of the centroid gives us the X position of the mirror, while the minimum and maximum coordinates define the "safe zone" around the head.

To prevent the noise in depth data to affect the position of the mirror, we perform a smoothing over time by averaging the mirror positions of the last N frames (N typically equals 2 or 3).

The above algorithm is obviously very specific to our configuration, but it has the advantage of being simple to implement and very fast to compute.

2.5 Interaction with virtual targets

To help the patient focus his attention on the movements of the virtual arm, the system implements a very simple game which consists in popping up virtual objects of various shapes and sizes in random positions. The patient is requested to touch these targets with the hand or the fingers of his virtual arm, and when the target is hit, it turns red and disappears. Then, another target appears somewhere else in the game area.

The detection of the "collision" between the hand and the virtual target is done by counting, for each frame, the number of vertices that are located inside the bounding box of the target. If this number exceeds a certain threshold, whose value is a parameter of the system, the target is considered as being touched.

2.6 Usage scenarios

We have defined two usage scenarios. The first one consists in applying a virtual mirror to the scene, vertically, so that half of the body of the patient is symmetrically duplicated with regards to the plane of the mirror, as illustrated in Figure 4. The patient has the impression that he is moving both the affected and the non-affected arms.

The second scenario simply consists in inverting the 3D image horizontally, letting the patient observe the reflection of his uninjured arm as if it was the injured one (Figure 6). This scenario is technically speaking a lot easier than the first one because we just have to invert the X coordinates of the mesh vertices.

2.7 Typical course of a therapy session

A typical therapy session has a duration of about 15 minutes. It is divided in two phases. First the patient performs some simple exercises with the non-affected arm and watches the virtual movements of the affected arm. The exercises typically are flexions and extensions of the hand, radial-ulnar inclinations of the wrist or tip to tip finger movements.

After that, the patient plays a game where he has to touch, with his virtual hand, virtual targets of different sizes and shapes that appear in random positions in a specific subset of the 3D space called the "game zone" (Figure 7). The difficulty of the game is progressively increased by asking him to first touch the target with the palm, then with the fingers, then to grasp it with the whole hand and finally to grasp it with just the fingers.

Figure 6. *Illustration of the second scenario: the patient moves his right arm, but he sees its reflection on the other side, as if he was moving his left arm.*

Figure 7. *The patient plays a game where he has to touch virtual targets with his virtual limb. The two parallelepipeds drawn in cyan wireframe represent the "game zone" where the virtual targets appear.*

3. RESULTS

All the results presented here have been acquired according to modern ethical standards and have been approved by the ethical committee of the Erasme hospital.

The system has been tested on 8 patients, 7 of them suffering from CRPS and one from PLP after amputation. For each patient, the Table 1 describes the age, the gender, the duration in months of the injury, the initial cause of the pain problem, the affected side and the currently prescribed medication. The medication was not modified or suspended during the treatment.

During the sessions, after five minutes of exercises, the patients have reported one or more of the following effects on the injured side: regional anesthesia, heaviness, tingling, swarming, sleeping effect, sweating.

Figure 8 summarizes the results of the clinical tests. The blue bars represent the pain intensity before starting the therapy session. The violet bars represent the pain intensity at the end of the session. Each patient has performed minimum six sessions and the pain intensity evaluations have been averaged on all the patients. Pain was measured on Visual Analogic Scale (VAS), and we asked the patient to report after how many time the pain reappeared.

From the results obtained for the whole population (Figure 8, left), it may be observed that: (1) the pain intensity decreases on average by 24% between the start and the end of a single session, (2) there is a

persistence effect as the PRE value progressively decreases from one session to the next, and (3) after five sessions, the global pain decrease is of about 32%, on average.

From the results obtained for the sub-population of the four highest responders (Figure 8, right), it may be observed that: (1) the average pain decrease per session is of about 28%, (2) the persistence effect is even stronger, and (3) after five sessions, the average global pain decrease is of about 50%.

We also observe that the pain reduction effect induced during the training persists after the session, during a certain number of hours, and that the duration of this persistence increases with the number of sessions performed (Figure 9). For one patient, the pain totally disappeared after 4 sessions, and for another one after 10 sessions.

Table 1. *Description of the subjects submitted to clinical tests.*

Subjects	Age	Gender	CRPS or PLP duration	Cause	Affected side	Prescribed medications
Case 1	48	♀	6	TFCC	Left	Clonazepam
Case 2	37	♂	12	Tenolysis	Right	Tramadol, amitriptyline, paracetamol
Case 3	39	♂	5	Suture tendon extensor	Left	Calcitonine, clonazepam, chlorhydrate tramadol, corticosteroïd, pregabaline
Case 4	75	♂	4	Distal radius fracture	Left	Duloxetine, paracetamol
Case 5	63	♀	16	Wrist instability	Right	Nothing
Case 6	47	♀	26	Trapezectomy	Right	Oxycodone, clonazepam, amitriptyline, duloxetine
Case 7	37	♀	26	Sauve-Kapandji	Right	Pregabaline, prazepam, amitriptyline, tramadol
Case 8	36	♂	60	Amputation	Left	Oxycodone

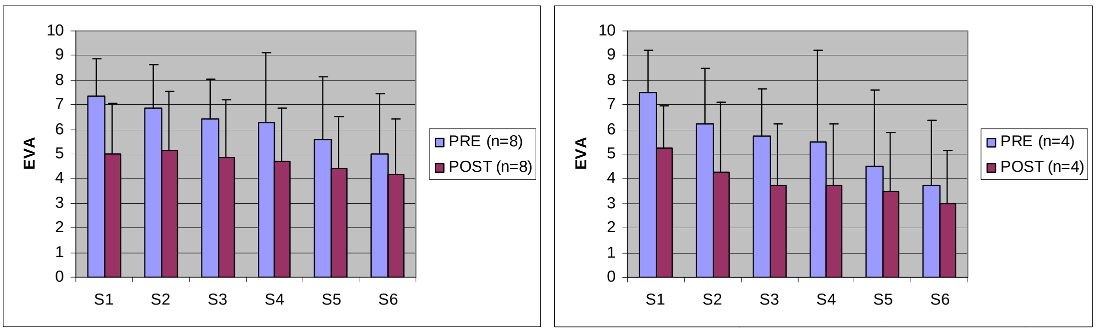

Figure 8. *PRE and POST pain intensity evaluation for the whole population (left) and for the four highest responders (right).*

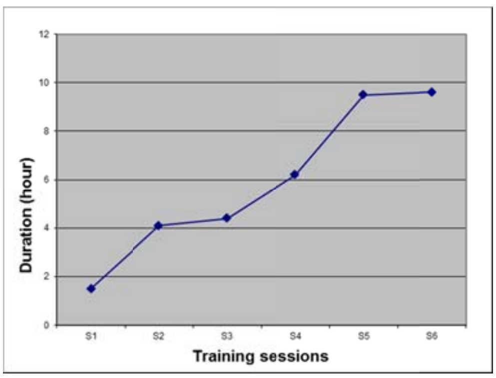

Figure 9. *Persistence duration of the pain reduction effect as a function of the number of training sessions.*

For two subjects, we completed our assessment by measuring a thermal perception and thermal pain threshold with the Neuro Sensory Analyzer (Medoc®). From this measure we have clearly observed a modification in the detection of sensibility (detection was delayed like a hypoesthesia) and also in the perception of pain (almost the same level as of controlateral side). It is too early to draw conclusions from this, but it confirms the symptoms evoked by the patients (anaesthesia, insensibility, decrease of pain …).

In the future, as proposed by Novak and Katz (2010), in order to confirm our results we will include in our assessments the measures of the physical impairment such as range of motion, strength, and sensibility. Pain assessment using a neuropathic pain scale, like the Mc Gill pain questionnaire to asses both neuropathic and nociceptive pain, will provide information on the intensity of pain. But also self-reported questionnaires such as the Disability Arm Shoulder Hand (DASH), and questionnaires to evaluate for symptoms of depression, pain catastrophizing or fear avoidance will be useful in identifying concomitant psycho-social factors that may affect outcome.

4. CONCLUSIONS

We have developed a system that applies techniques of augmented reality to the principle of the mirror visual feedback. It strengthens the patient immersion and concentration on the movements of the virtual injured arm through the use of 3D image acquisition and display. Since we directly use the 3D and color data from the camera, the generated images are very natural looking, and the patient's illusion that he is moving his injured arm is strengthened. The inclusion of a game where the patient must touch virtual targets positioned randomly in 3D space, allows him to stay focused on the movements of the injured arm throughout the session. It also enables to reduce his anxiety. The system is simple to install and use: the patient must not wear any specific tracking equipment or markers. He simply has to sit in front of the camera and watch the screen with 3D glasses. In addition, through the use of technologies widely available on the market, the system is low cost. All this make our system perfectly suited for use in a therapist's practice or even at home.

The results presented here are preliminary and should be confirmed by a randomized control study on a larger population.

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Augmented reality improves myoelectric prosthesis training

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ABSTRACT

This paper presents the ARM Trainer, a new augmented reality-based system that can be used to train amputees in the use of myoelectric prostheses. The ARM Trainer provides users with a natural and intuitive method to develop the muscles used to control a myoelectric prosthetic. In addition to improving the training process, the new interface has the potential to mitigate psychological issues arising from amputation that are not addressed by existing approaches (e.g., self-image, phantom limb pain). We conducted an empirical study comparing our system to an existing commercial solution (Myoboy) and found the ARM Trainer to be superior along a number of subjective dimensions (enjoyment, perceived effort, competency, and pressure). We also found no significant difference in terms of muscle control development between the two systems. This study shows the potential of augmented reality-based training systems for myoelectric prostheses.

1. INTRODUCTION

Following the loss of a limb, amputees face a number of problems including adapting to a new body image, relearning how to perform simple tasks, and coping with psychological and physical pain. Prosthetics can alleviate many of these difficulties, but require a great deal of skill to operate efficiently. Myoelectric prostheses monitor muscle activity using surface electromyography (sEMG). As amputees contract specific muscles, the sEMG system detects the change in the electrical signal from the muscle and uses it to drive a set of motors within the prosthetic device. Amputees need to learn how to control the contraction of their muscles, in particular the level of activation of the muscle, and how to isolate independent muscles. A substantial training period is required before amputees can reliably use their myoelectric devices.

There is often a long delay between amputation and receipt of the custom prosthetic. While waiting for their prosthesis, therapists work with an amputee and encourage them to voluntarily activate target muscle sites (e.g., “Try to contract your biceps”) (Dupont and Morin, 1994; Smurr et al., 2008). This is a challenging task, as there is little or no feedback provided to an amputee about their progress and the exercise is monotonous. When a prosthetic device arrives, the amputee can begin training with the actual device, but often experience irritation on their residual limb from the device. This prevents training for any extended periods of time. Amputees who do not receive a prosthetic limb soon after amputation are unlikely to ever use them in daily life. Instead, many amputees learn how to perform tasks unimanually. By the time their prosthetic limb arrives, they often feel that it is more troublesome to learn how to effectively use the prosthetic limb than to continue with their unimanual life (Burkhalter et al., 1976). Training administered prior to arrival of the prosthetic has been seen as an important component in the long-term success of amputees. Several software (Al-Jumaily and Olivares, 2009) and hardware (Dawson, 2012) training methods have been devised. One approach to training is to use a software system such as the Myoboy software suite (OttoBock, 2011), which records sEMG signals and processes them in real time. The Myoboy is a commercial product targeted towards prosthetics training and includes a simple video game controlled using biofeedback. In the game, users are asked to navigate two cars through a series of gates, with the height of each car being proportional to the activity at one of two muscle sites. The game is quite rudimentary, and as such there are many areas that its simple interface neglects (e.g., ease of use, interactivity, and the use of more than two channels). Other groups have developed similar game-based training systems that map muscle activity to on-screen actions. In one system, muscle activity was mapped to paddles in an adapted version of the classic Atari game, Pong (de la Rosa et al., 2008). In another system, users were able to play a modified

version of Guitar Hero by activating their muscles (Armiger and Vogelstein, 2008). While these approaches provide engagement and motivation, they require actions that are unintuitive and do not map well to the final prosthetic. Others have chosen to map muscle activity directly to virtual prosthetics (Murray et al, 2006; Al-Jumaily and Olivares, 2009). These projects have shown that training using a virtual prosthetic may be effective, but there is still substantial room for improvement. Most systems employing a virtual prosthetic do not include engaging environments, instead focusing solely on the actuation of the joints, which can become monotonous. Additionally, the virtual representation is often a depiction of a prosthetic on-screen; there is no connection to the user's body. We point the reader towards Dawson's work for an extensive review of myoelectric training systems (Dawson, 2011).

The ARM Trainer has potential to improve an amputee's body image and decrease phantom limb pain, both of which are common afflictions in amputees (Hanley et al., 2004; Desmond, 2007). Self image issues arise when amputees reject their new body image or having trouble adjusting to the new way that they look. Phantom limb pain is a condition where a recent amputee seems to experience pain in the limb that was amputated. To treat this pain, amputees are often placed in front of a mirror-box that reflects their intact limb, so they perceive themselves as having two intact limbs (Ramachandran and Rogers-Ramachandran, 1996). This procedure is often successful, but in some cases the pain an amputee feels persists and virtual reality treatments may be administered (Murray et al., 2006). These problems may be treated by the ARM Trainer, as the amputees can see themselves with two intact arms or with a virtual prosthetic.

We have explored the use of augmented reality as a tool for training muscle control and developed a software interface, the Augmented Reality Myoelectric (ARM) Trainer (Figure 1), to provide a more natural and engaging interface to train for myoelectric prostheses. With this system, amputees are shown a real-time video of themselves with a virtual arm overlaid on their residual limb. The amputee controls this virtual arm by contracting the same muscles that will be used to control their prosthetic. This not only provides an intuitive interface for mapping the muscle activity to arm movement, but also provides a unique, personalized training interface.

2. THE ARM TRAINER

The ARM Trainer is a training system for myoelectric prosthetics that provides an intuitive and engaging way for users to learn to control their muscle activity. The system presents users with a real-time mirrored view of themselves with a virtual arm overlaid on their residual limb. Users are able to control this virtual arm with their muscles and use the virtual arm to play a game (Figure 1).

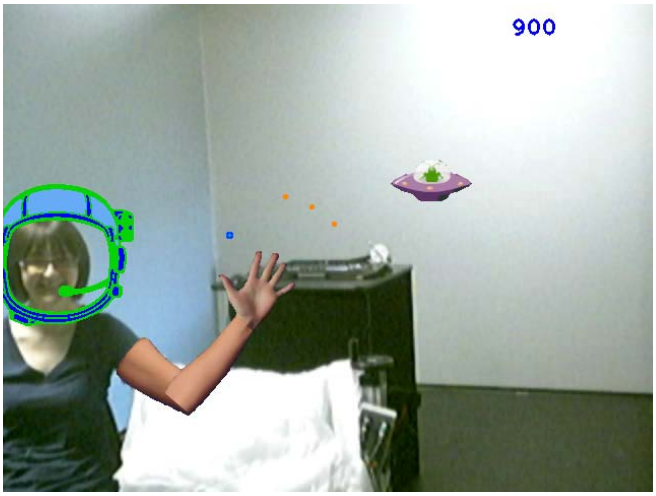

Figure 1. *The ARM Trainer system, as displayed to the user.*

The system is designed to be easy to use and is relatively portable. The custom software (written in the C programming language) combines signals from an EMG amplifier, a model of a virtual arm, and a live video feed. The system is run on a laptop running Windows 7 with a built-in webcam. The only additional hardware required is an EMG amplifier, which is required for all prosthetic trainers. This system is simple to configure and use, with minimal setup and an automated calibration procedure. As therapists have limited time with patients, ease of use is of the utmost importance. In addition, if users are to take the system home and practice outside the clinic, it must be robust and easy to use.

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2.1 sEMG Signal Processing

During voluntary muscle contractions, the motor units of skeletal muscles generate electrical potentials that can be detected on the surface of the skin using sEMG. In our system, the sEMG signal is detected and amplified using a Bortec AMT8 system (Bortec, 2011). To digitize the signals from the AMT8 system, a USB National Instruments Data Acquisition System samples 4 channels at 2000 Hz. As the potentials generated by the motor unit result in a complex oscillating signal, the raw data need to be rectified and filtered to be viable for controlling the virtual prosthetic. An approximation of the signal envelope is computed for each channel by applying a root mean square (RMS) filter with a window size of 400 milliseconds to the raw data points.

2.2 sEMG Calibration

As the voltage detected by the electrodes varies widely between users, calibration of the sEMG signal was required. The voltage is dependent on muscle characteristics, the amount of tissue between the muscle site and the skin, and the electrode placement. For a user with weak muscles and high body fat, for instance, the potentials are quite low. If an electrode is not placed directly over a muscle site, there can also be a reduction in the detected signal. By performing the calibration procedure, the system becomes flexible enough to be quickly configured by a home user or a therapist with limited time.

To calibrate the system and determine appropriate gain values (k_i), users are asked to maximally activate each muscle site individually. The system monitored each channel and determines the maximum level of activation. For each of the four channels, the gain value for k_i was set to 1 / 70% of the maximum value of the filtered signal. The value of 70% was derived from pilot studies and represents a comfortable level for people to operate the arm without becoming quickly fatigued. Once the calibration is complete, the resulting k_i values are stored for later use. When the calibrated values are used later, a ceiling function is applied so all values fall within the range [0, 1].

2.3 Virtual ARM

The virtual arm is composed of three photo-realistic segments: a hand, forearm, and shoulder. The forearm and shoulder segments were taken from a still photo of an arm against a chroma key background. The shoulder of the arm was segmented from the background and overlaid at the determined location. The forearm was similarly segmented, aligned to the shoulder segment, and rotated to the calculated elbow angle. The position and orientation of the virtual shoulder can be adjusted using the mouse to manually align the virtual arm with the participant's natural arm. In a clinical deployment, one could place fiducial markers on the amputee's residual limb to locate it within the video stream and automatically align the virtual arm. The hand segment was taken from a 24 frame video sequence of a hand opening and closing against a chroma key background. After selecting the appropriate frame of the video based on the degree of hand closure, the hand is aligned to the distal end of the forearm. The resulting arm is composited with the input video sequence and displayed to the user.

As the user's muscle activity is used to control the movement of the virtual arm, the envelopes of the signals were used to drive the flexion and extension of the virtual elbow, as well as the degree of hand closure. The envelope for each signal (s_{it}) was first multiplied by the channel gain term (k_i) and the resulting value was used in conjunction with the opposing signal as proportional control for the parameters of the virtual arm (θ_{elbow_t} , θ_{hand_t}).

$$\theta_{elbow_t} \propto \theta_{elbow_{t-1}} + k_{biceps} \cdot s_{biceps_t} - k_{triceps} \cdot s_{triceps_t} \tag{1}$$

$$\theta_{hand_t} \propto \theta_{hand_{t-1}} + k_{flexor} \cdot s_{flexor_t} - k_{extensor} \cdot s_{extensor_t} \tag{2}$$

Extension of the virtual elbow joint is accomplished by maximizing the contraction of the triceps while minimizing the contraction of the biceps. Flexion of the virtual elbow is achieved through maximal contraction of the biceps and minimal contraction of the triceps. Similarly, the hand is opened by contracting the muscles on the forearm's flexor muscles and closed by contracting the forearm's extensor muscles. Use of these muscle groups provides a very natural interface for controlling the virtual arm, as there is a direct mapping from natural movement in the real world to movements of the virtual arm. Only one arm model was used in the empirical study. In clinical use, therapists could easily add a model of the amputees' intact limb, allowing them to have a more realistic experience.

2.4 Space ARMada

The gaming element of the system, Space ARMada, features the user as a space explorer who must defend themselves against aggressive, invading spaceships. A space helmet is overlaid on the users' head and spaceships appear sporadically on screen at different locations. The user's goal is to shoot the spaceships down (using the virtual arm as a canon) before being shot at by the spaceships. Points are awarded for successfully destroying a spaceship and deducted if the spaceship fires at the user. Users must alternate between fully open and closed hands to shoot bullets from the hand.

This game trains muscle control by requiring large, fast movements when the arm is pointing far away from the spaceship and finer movements as the arm approaches the correct position. The users can vary the spread and speed of bullets by controlling the speed of hand closure, thus encouraging them to vary their level of activation. As the control is proportional and co-contraction results in a slower movement, muscle independence is encouraged. In addition, the system encourages independence between the forearm and upper arm, as the elbow must remain stable while the hand is opening or closing to remain on target.

3. EMPIRICAL STUDY

An empirical study was conducted to evaluate the effectiveness of The ARM Trainer for muscle training as well as to gather users' subjective opinions of the system. The ARM Trainer was compared to a custom-written software game that mimics the functionality of the commercial Myoboy game. With the custom software (Myoclone, Figure 2), we could record complete data and have users operate both systems without exchanging electrodes. All participants used both the Myoclone system and the ARM Trainer, with the order randomized across participants. Twelve healthy volunteers (6 female, M = 26 years, SD = 3.4 years) participated in the study. While the results are not guaranteed to translate from the healthy population to amputees, this study can provide many insights into the design of training systems. The University of Alberta Arts, Science, and Law Research Ethics Board approved the study.

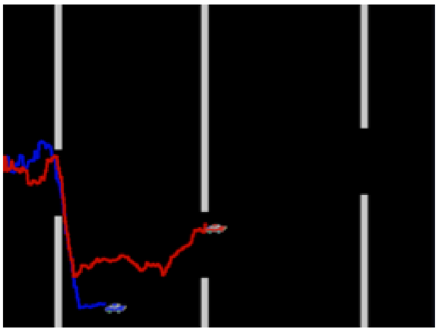

Figure 2. *In the Myo-boy clone, muscle activation controls the vertical position of the cars (e.g., red (top) car controlled by biceps, blue (bottom) car controlled by triceps). The cars move automatically from left to right. The user's goal is to steer the cars through the gaps in the walls.*

At the beginning of the experiment, four muscle sites (i.e., the biceps brachii, triceps brachii, and the muscles used for flexion and extension of the hand: palmaris longus, flexor carpi ulnaris, extensor carpi ulnaris, extensor digitorum) were located on the right arm of the participant. To increase the similarity between the normal population and the target amputee population, two additional steps were taken. First, the participant's arm was immobilized in the apparatus depicted in Figure 3a to prevent it from moving during the experiment. In addition, a white sheet was placed over the participant's arm to ensure that they focused on the virtual arm and not their own arm during the experiment.

Participants then performed the calibration procedure before beginning their baseline muscle control evaluation. The participants' ability to control their muscles was evaluated using a set of bar graphs representing their muscle activity in real time (Figure 3b). They were asked to match their muscle activity to three targets that were presented in sequence at 33%, 66% and 100% of calibrated muscle activity. Each target was active for 8 seconds followed by 8 seconds of rest. Each channel was evaluated in sequence, for a total of 12 targets. Participants were instructed to minimize co-contraction during this task.

As the original Myoboy software only process two signals simultaneously, the Myoclone phase of the experiment was split into two five-minute training segments. In the first segment, participants used their

forearm muscles to control the height of two cars (by flexing and extending the hand) to navigate the onscreen cars through the gaps in the white gates. In the second segment, participants used their upper arm muscles to perform the same task. Before the training phase, participants were given a brief period to become accustomed to the interface. The ARM Trainer phase consisted of one five-minute session. In the ARM Trainer phase, users played Space ARMada, with the goal of eliminating as many spaceships as possible. Prior to the ARM Trainer phase, each participant had a brief period to become familiar with the interface. While the total time with each system differed, the time spent using each muscle group was the same.

To measure subjective opinions about the game, an adapted version of the Intrinsic Motivation Inventory (IMI) (McAuley, 1989) was used. The IMI is a validated questionnaire that assesses participants' subjective opinion towards an activity and evaluates the activity along four dimensions: enjoyment-interest, competency, effort-intensity, and tension-pressure. The questionnaire includes statements such as 'I enjoyed this game very much' and 'I am satisfied with my performance on this game'. Participants' responses were recorded on a 5-point Likert scale. The questionnaire was administered following each training system.

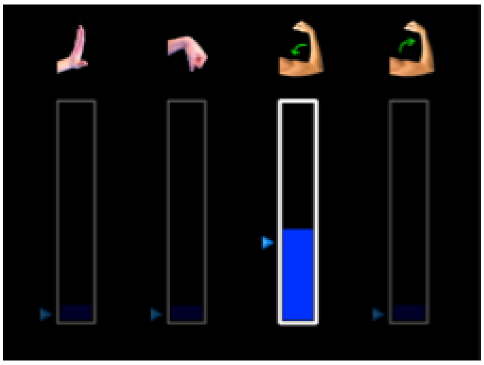

Figure 3. *a) sEMG electrodes placed on a participant in the immobilization apparatus. b) Task used for calibration, as well as the evaluation of muscle activation and isolation. Participants were asked to contract the specified muscle site to the level indicated by the highlighted triangle while minimizing the contraction of the other three muscle sites.*

4. RESULTS

Responses to the IMI were compared using a Wilcoxon signed rank test. For all dimensions, the responses related to the ARM Trainer were significantly better than those related to the Myoclone (Figure 4). Participants reported feeling more interest and enjoyment ($p < 0.01$) and felt more competent at playing the game ($p < 0.01$). Participants also reported that the ARM Trainer seemed to require less effort than the Myoclone ($p < 0.01$), and they felt less tension and pressure while playing ($p < 0.05$).

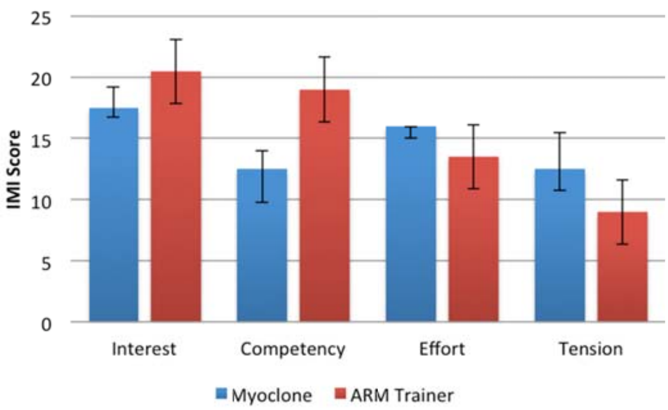

Figure 4. *Responses to IMI questionnaire, error bars show upper and lower quartile of participant responses.*

Muscle isolation was calculated by computing the Pearson correlation between the signals for each channel during the evaluation phase. High correlation between the signals from two muscle sites indicates a high degree of co-contraction of the underlying muscles. The improvement in muscle isolation for each system is the difference between the post-system correlation coefficient and the baseline correlation coefficient for each pair of muscles. This results in six values corresponding to the pairs of muscles (Table 1).

Table 1. *Improvement in isolation following each training system (Myoclone / ARM Trainer). Values represent the unitless change in correlation between each muscle site.*

Muscle Site	Flexor	Biceps	Triceps
Extensor	0.08 / 0.10	-0.01 / -0.05	-0.09 / 0.06
Flexor	-	-0.08 / -0.05	-0.06 / 0.00
Biceps	-	-	0.06 / 0.03

Muscle isolation was analyzed using a paired Z-test on the Fisher-transformed correlation coefficients of each pair of signals. No significant difference with respect to muscle isolation ($p > 0.05$) was found between the ARM Trainer and the Myoclone. Both systems showed small positive improvement in reducing the co-contraction of antagonistic muscles (e.g., biceps and triceps), but no improvement reducing the co-contraction of non-antagonistic muscles (e.g., forearm extensor and biceps).

The accuracy of muscle control was computed as the squared difference between the target (33%, 66%, 100%) and the filtered and scaled muscle activity. For each evaluation, this yields 12 accuracy values (3 for each of the 4 channels). The improvement in muscle control is the difference between the post-system accuracy and the baseline accuracy. Muscle control was analyzed using paired t-tests comparing the post-Myoclone improvements to the post-ARM Trainer improvements. As with the muscle isolation results, no significant differences were found between the two systems. The results show no pattern of improvement in the accuracy of activation with either the Myoclone or the ARM Trainer (Table 2). This is likely due to the short duration of the pilot study.

Table 2. *Improvement in muscle control accuracy following each training system (Myoclone / ARM Trainer). Values represent the unitless change in squared error from the target.*

Muscle Site	33%	66%	100%
Extensor	0.004 / 0.004	0.000 / 0.000	-0.006 / -0.005
Flexor	0.000 / 0.000	0.000 / 0.000	-0.021 / -0.005
Biceps	-0.005 / 0.000	0.001 / 0.000	-0.017 / -0.020
Triceps	-0.005 / 0.0000	0.002 / 0.000	0.056 / 0.068

5. DISCUSSION

Our study of the ARM Trainer shows that it provides an improved user experience over the current standard of care. Participants reported high levels of interest and enjoyment with the ARM Trainer, which could stem from several factors. The novelty of the augmented reality could play a large role as many participants were not familiar with the technology. Several participants laughed, or made positive statements such as 'That's cool!' upon seeing the video of themselves with the virtual arm and space helmet. The game design and visuals may be a factor in the increased enjoyment as well, as the ARM Trainer had more actions to perform, different subject matter and more detailed graphics. Some participants commented that they felt the arm was a natural extension of their body during the trials, even though the arm was clearly an overlay on the image. This is encouraging for the potential treatment of phantom limb pain and self-image issues. If effective, this would be the first EMG-driven treatment option for phantom limb pain, and a step forward for improving the well-being of recent amputees.

The increased competency and decreased effort reported by participants are likely related. The intuitive and natural mapping of the interface plays a role in this, as the actions required less cognitive resources to execute. The reports of decreased effort may stem from an increased engagement in the game and a reduced focus on generating the required muscle activities. It was also evident that several participants had become bored with the Myoclone game, as they began repeatedly making errors by contracting the wrong muscle and then quickly correcting it. The reduced tension and pressure is likely related to the increased enjoyment, as participants were having more fun, making it feel less like training. Feedback may also have played a small

role, as a small explosion was immediately displayed in the Myoclone after an error, whereas participants could miss the spaceship a number of times before the spaceship fired back.

The muscle isolation results are encouraging, as the ARM Trainer performed no worse than the Myoclone, even though the Myoclone is targeted specifically at reducing the co-contraction of antagonistic pairs. The improvement in muscle isolation following the ARM Trainer can be attributed to the proportional control of the virtual arm that requires minimization of the antagonistic muscle to achieve movement of the virtual arm. While there was no improvement on non-antagonistic pair co-contraction in our study, we are optimistic that a long term study would show benefit, as the ARM Trainer requires participants to contract multiple muscle sites to perform optimally. Adding direct biofeedback may allow better development of muscle isolation with the ARM Trainer. Several participants struggled initially with the ARM Trainer due to co-contractions. For instance, while trying to extend the elbow, participants contracted the triceps (correct site), but also contracted the biceps (incorrect site), resulting in a net-zero movement for these actions. Participants responded by trying to increase contraction, which tended to only worsen the co-contraction and increase frustration. Direct visualization of the muscle activity for each channel would allow participants to see the co-contraction and respond appropriately.

Our approach has several limitations. Notably, we present a system specifically tailored for trans-humeral amputees. It is easy to imagine a similar system with two degrees of freedom, and only a virtual forearm and hand for below-elbow amputees, but it is more difficult to generalize to lower-limb amputees. An increased suite of games to keep amputees engaged longer, as well as providing additional measures and information on-screen to motivate amputees would improve the system. Additionally, the measures of muscle accuracy are likely not relevant for short task durations. In the initial baseline test, most participants were able to quickly match their muscle activity to each target without much difficulty. More reliable measures of muscle accuracy may be obtained by making this task more difficult by increasing the number of target levels. In addition, any small improvements in muscle activity may have been cancelled out due to fatigue.

6. CONCLUSIONS AND FUTURE WORK

We have shown the potential for augmented reality for myoelectric prostheses training. Our AR-based prosthetic training system allows natural control of a virtual arm using four sEMG channels. Our ARM Trainer performed at a level similar to existing methods in developing muscle control. More importantly, the use of augmented reality was shown to provide a better user experience than traditional game-based systems. This study paves the way for the use of augmented reality in amputee training. A long-term study is currently under development for amputees at a local rehabilitation clinic. This future study will allow self-image and phantom limb pain to be fully explored in the target population.

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Development of an augmented treadmill for the rehabilitation of children with cerebral palsy: pilot perspectives from young healthy adult users

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ABSTRACT

A Real-time Treadmill Speed Control Algorithm (RTSCA) has been developed for gait rehabilitation of children with cerebral palsy (CP). The objective of the work described in this paper was to investigate the feasibility of the RTSCA prior to use by children with CP. Thirteen healthy subjects aged between 19 and 25 were recruited to walk on the treadmill using conventional speed buttons without the virtual reality (VR) environment, and the RTSCA with and without VR. The participants were asked to undertake three treadmill tests and to complete a questionnaire to provide feedback on the control of the treadmill. The descriptive results show that for 10 participants changing walking speed from stationary when using the RTSCA was similar or more comfortable to using conventional treadmill speed control buttons. For those who found it less comfortable the core issue was insufficient time to practise with the system. All the participants were satisfied with the safety and the performance of the RTSCA when incorporated into the VR scenario. A Wilcoxon test was conducted to examine whether there was a significant difference between walking speeds on the treadmill when using the conventional speed buttons and the RTSCA. The results showed that participants walked at significantly higher speeds when using the RTSCA. This may suggest that they walked more naturally or confidently on the treadmill when using the RTSCA as compared to the use of conventional treadmill speed control buttons.

1. INTRODUCTION

Cerebral Palsy (CP) refers to a set of disorders that can affect the progress of movement and posture, resulting in a limitation of activity [Gage, 1991]. The mobility of children with CP is normally better if the management of CP is provided effectively. Management focuses on using suitable combinations of interventions often through a multidisciplinary team. An important element of this management is gait (walking) rehabilitation often provided under the guidance of physiotherapists. However, staffing and clinical space allocation can limit the number of gait rehabilitation sessions that can be provided. In addition, some patients can find it difficult to maintain an appropriate level of motivation, particularly when sessions are undertaken in unrealistic environments or conditions.

Treadmill training is considered as a likely method to address some of these limitations. The potential of rehabilitation based treadmill training for children with CP has been recognised by previous research [Lancioni et al., 2009, Zwicker and Mayson, 2010]. The development of treadmill training is based on the motor learning theory which suggests that repetitive practise of the skills that need to be developed is important in re-learning those skills [Lancioni et al., 2009, Zwicker and Mayson, 2010]. Motivation on the part of the child, however, remains an issue [Lancioni et al., 2009]. The inclusion of a virtual reality (VR) environment into training which can then become, for instance, a structured 'game' that the child can become immersed in, is a possible approach to engaging children who might otherwise lack the motivation needed to complete a prescribed rehabilitation programme.

VR can be defined as an approach that allows users to interact with a computer simulated three-dimensional (3D) environment [Burdea and Coiffet, 2003]. It has been used in medical applications such as

rehabilitation and health care training. VR has been shown to facilitate rehabilitation sessions in a safe environment which then encourages patients to engage their sessions with higher attention [Rizzo and Kim, 2005, Rizzo et al., 2004]. The literature suggests that VR based gait rehabilitation for post stroke survivors can be more effective than conventional (over-ground) and treadmill based rehabilitation [Deutsch and Mirelman, 2007]. For children with CP, VR can help to increase self-confidence and motivation, resulting in improvements in upper extremity function [Parsons et al., 2009,Sandlund et al, 2011,Snider et al., 2010]. Recent literature also shows the potential for the use of games during lower extremity rehabilitation [Kott et al., 2009,Parsons et al., 2009,Snider et al., 2010]. However, further work is required in this area.

When using a treadmill, one of the issues with immersion is speed control, which conventionally is achieved by using buttons or controls on the treadmill. A powered but self-paced treadmill could be used to improve immersion; the treadmill speed responding to the speeding up and slowing down of the user, but without the need to use speed control buttons. The literature shows different techniques used in order to implement a general locomotion interface in a VR and/or for other purposes [Christensen et al., 2000, Lichtenstein et al., 2007, Manurung et al., 2010, Minetti et al., 2003, Souman et al., 2010, Von Zitzewitz et al., 2007]. A feedback-controlled treadmill locomotion interface was implemented based on a proportional - integral - derivative (PID) controller, with the difference between intended position and that from sensors attached to the user as input, and investigated by Lichtenstein *et al* [2007] and Minetti *et al* [2003]. The slow response of the treadmill to user movement on the treadmill was reported as one limitation in the study conducted by Minetti *et al* [2003]. In both studies, the PID control algorithm used to calculate treadmill speed is designed to maintain the user's walking at a certain preset position on the treadmill. Due to the limited ability to change walking speed with this approach, users may not feel that they can walk naturally at a range of speeds on the treadmill. Christensen *et al* [2000] and Von Zitzewitz *et al* [2007] adapted the treadmill speed based on the force applied through a cable attached to a mechanical tether on the back of the user; the force changing as the user moved forward or backward during their walking on the treadmill. A limitation of this approach is that the attached tether may interfere with focusing solely on the activity. To address this, Manurung *et al* [2010] adapted a speed control treadmill algorithm based on the use of a sonar sensor, which was placed on the user's back. The sensor determines how far the user is on the treadmill from a predefined reference point, and this distance in used by the algorithm to determine the walking speed. The approach demonstrated in this study enabled users to adjust their walking speed on the treadmill successfully; however, an approach is required to increase level of immersion and clinical applications (e.g. biofeedback and 3D kinematic) that can be associated with augmented treadmill training. One approach to addressing these concerns could be the use of optical motion capture systems that rely on small light-weight markers that can be attached readily to the user's body [Souman et al., 2010]. Such an approach can be used not only to control speed using a position based algorithm with a simple array of markers, but through use of more complex marker sets, determine the placement of body segments in space to enhance the immersion of users in a virtual world. For this reason a motion capture based Real-time Treadmill Speed Control Algorithm (RTSCA) was developed as part of the Surrey Virtual Rehabilitation System (SVRS) [Al-Amri et al., 2011].

Before evaluating the RTSCA with children with CP it was considered necessary to investigate its use in people with unimpaired ambulation. For convenience, a group of young healthy adults was selected. This paper presents their perspectives on the safety and performance of the RTSCA. The hypothesis was divided into three parts as follows:

- H1: participants would find walking on the treadmill when using the RTSCA to be at least comparable in comfort and safety to that when using conventional treadmill speed control buttons
- H2: participants would be unable to walk on the treadmill under the RTSCA successfully and efficiently to complete a walk across a virtual city requiring regular speed adjustment
- H3: walking speeds on the treadmill when using conventional treadmill speed buttons would not be significantly different to those with the RTSCA

2. METHOD

2.1 Real-time Treadmill Speed Control Algorithm

The RTSCA is based on an open loop PID controller algorithm implemented in the Vizard Virtual Reality software (version 3.18.0002, WorldViz LLC, USA). It enables users to start walking on a stationary treadmill (PPS WoodWay treadmill, WoodWay, Germany) and for the treadmill speed to respond to their movement. Users wear a pelvis reflective marker 'cluster' (see Figure 1) and two reflective markers on their feet, the latter to stop the treadmill if users step outside the treadmill belt. The Qualisys optical infrared tracking system (version 2.4.546, Qualisys AB, Sweden) is used to track marker positions. The software calculates the

longitudinal difference between the pelvis cluster origin and the treadmill origin point; this difference (x_e) is then used to compute the Calculated Treadmill Speed (CTS) as illustrated in equation 1. The CTS is sent to the treadmill through a RS232 serial connection.

$$CCTS(t) = k_p \times x_e(t) + k_d\{x_e(t) - x_e(t-1)\} + k_i \sum x_e(t) \qquad (1)$$

K_p, K_d, and K_i are the coefficients for the proportional, derivative, and integral terms, respectively that were calculated using the Ziegler–Nichols method [Xue et al., 2008].

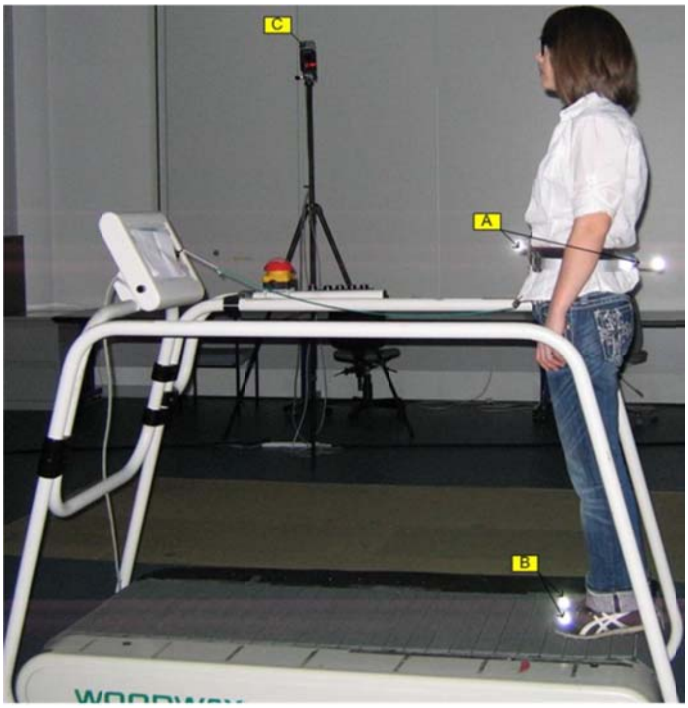

Figure 1. *A participant using the RTSCA. A: pelvis cluster – a sprung loaded frame with 3-point contact to calculate the origin of the pelvis segment; B: markers on feet; C: one of the eight motion capture cameras used.*

The PID control algorithm was tuned in trial experiments with 5 volunteers during which the treadmill speed changed when different values of the PID coefficients were tested. As a result, the optimum coefficient values were chosen as those that enabled users to walk with stable treadmill speeds with a maximum fluctuation of approximately 0.015 m/s (considered to be not noticeable) which was based on the responses from the test volunteers, and with the flexibility to increase walking speed gradually from zero up to a maximum walking speed of 1.9 m/s. Figure 2 shows four trials from a test with one user with different values for the PID coefficients. In the first and fourth trials, the fluctuation was noticed and the user took longer to reach their normal walking speed. The second trial did not enable the user to maintain a comfortable walking speed without unacceptable fluctuations in speed. The third trial allowed the user to walk at what they considered their comfortable walking speed without noticeable fluctuation.

Safety is clearly an important issue and the RTSCA is designed to trigger a controlled emergency stop, such that the system decelerates the belt speed to zero (at approximately 5 m/s^2) if any of the following occur:

- The user's pelvis obliquity, rotation, or tilt exceeds 25°
- The user steps outside the defined treadmill belt area, determined using the foot markers
- The connection between the treadmill and/or the marker detection system, and the controlling computer is interrupted

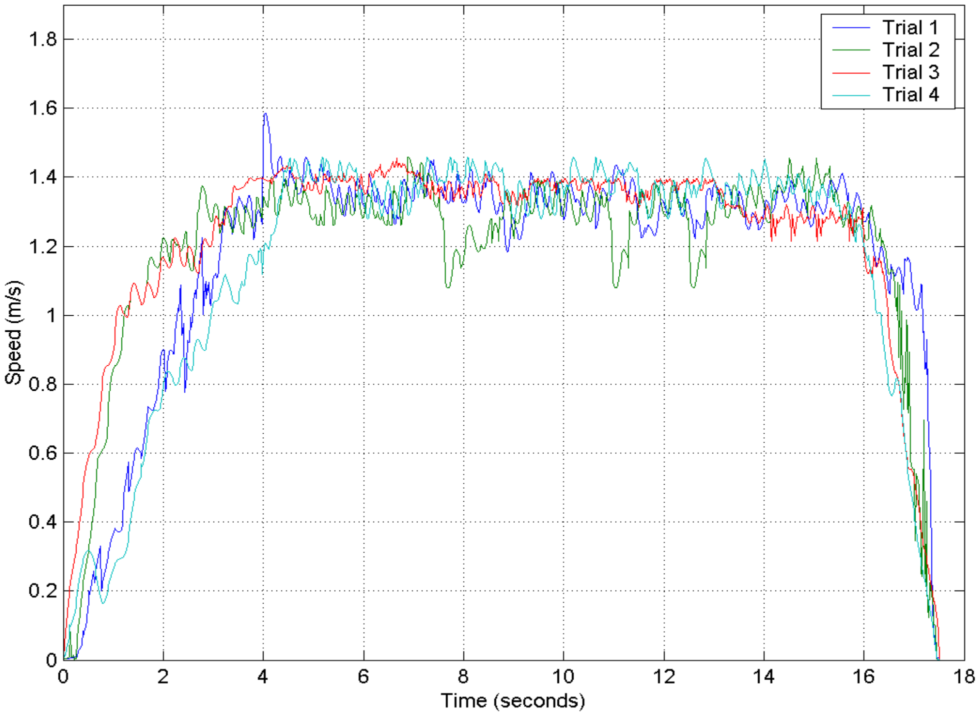

Figure 2. *Normal walking speed for different PID values.*

2.2 Research Participants

Ethical approval was granted by the University Ethics Committee. Criteria for inclusion in this investigation were: female or male; aged between 18 and 25 years; not involved in preliminary testing with the system; and able to answer 'NO' to all questions on a simple screening questionnaire (Table 1).

Table 1: *Questions in the Screening Questionnaire.*

No.	Question	No.	Question
1.	Have you any medical conditions that have affected your vision or walking ability in the past six months?	2.	Do you have photosensitive epilepsy?
3.	Do you experience dizziness during or after walking continuously for 10 minutes?	4.	Do you ever experience headache as a result of watching/using a TV or PC for 30 minutes?
5.	Are you unable to perform walking exercise for 10 minutes without taking a rest?	6.	Do you ever experience dizziness as result of watching/ using a TV or PC for 30 minutes?
7.	Do you have uncorrected problems with your vision?	8.	Do you ever experience nausea as a result of watching/ using a TV or PC for 30 minutes?

2.3 Procedure

The investigation was conducted in the Gait Laboratory at the University of Surrey and divided into three tests. Prior to performing these tests, participants had the opportunity to practise using the treadmill, particularly for those unfamiliar with using one in the past. Test one was designed to determine the participants' self selected slow, normal and fast comfortable walking speeds, when using the treadmill speed buttons without VR. In test two participants were asked to walk on the treadmill to reach self-controlled slow, normal and fast speeds using the RTSCA without VR. Both tests consisted of three trials; each was started with the participants standing at the origin point on the stationary treadmill. In the first trial of test one, the participants were asked to start walking on the treadmill until they felt they were walking at what they considered as their normal walking speed. The speed was monitored and they were asked to maintain

that speed for a further 20 seconds. Participants were then asked to reduce their speed to zero gradually. In the second trial, they were asked to follow the same procedure, but to walk at what they considered to be their fast walking speed. For the third trial, the participants were asked to walk on the treadmill at a slow walking speed for 20 seconds. They were then asked to change the speed to what they considered to be their normal walking speed and to maintain that speed for a further 20 seconds. They were then asked to change the speed to what they considered to be their fast walking speed and to maintain it for a further 20 seconds. After that, they were asked to stop safely by reducing their speed gradually to zero. At the end of this test, the participants were asked to complete 7 closed-ended questions.

In test two and after checking the motion capture system tracked all the reflective markers, the participants were asked to walk forward slowly to the (self selected) target speed for each of the trials following the procedure outlined in test one. At the end of the third trial, the research participants were asked to complete 11 closed-ended questions. For the third test, the participants were asked to walk forward slowly to reach their preferred self-selected walking speed in order to walk across a virtual city within a certain time (65 seconds). When walking across the city, they were asked to adjust their walking speed in order to avoid colliding with a virtual ball that appeared at random intervals for 5 seconds. At the end of this test, the participants were asked to complete 3 closed-ended questions and an open-ended question.

2.4 Statistical Analysis

The investigation was based on responses to a questionnaire that had two components. The first comprised 18 closed-ended questions and an open-ended question on the overall experience of walking on the treadmill as detailed above. The second was based on additional three closed-ended questions and an open-ended question that focused on the overall performance of the RTSCA when integrated with the virtual 3D scenario. The descriptive analysis and subsequent findings were obtained by using Microsoft Excel 2007. The data obtained by the open-ended question and the discussion with the researcher were also used to support the descriptive results of the closed-ended questions. A Wilcoxon test was conducted to examine whether there was a significant difference between walking speeds on the treadmill when using the conventional treadmill speed buttons and the RTSCA. The Statistical Package for the Social Science (SPSS) software for Windows was used to perform this test.

3. RESULTS

Thirteen young healthy adults (8 males, and 5 females), aged from 19 to 25 years (mean age was 22.15 ± 2.04) participated. The results from their responses are presented below.

3.1 Perspectives on the Treadmill when using Treadmill Speed Buttons

Seven closed-ended questions were asked to determine the perspectives of walking on the treadmill using conventional speed buttons. The responses are summarised in Figure 3. The results show that the majority of the 13 participants (9 and 11 respectively) found the ability and ease of accelerating from stationary on the treadmill at least as comparable to accelerating during normal over-ground walking. For the ability and ease to change from one constant speed to another, 11 and 10 participants respectively responded that it was at least comparable to what they do during their normal over-ground walking. None of the participants found the ability to maintain their walking speeds on the treadmill was worse than over-ground walking. For comfort in maintaining speed, 10 of them found it comparable to or better than over-ground walking. Nine participants found the comfort of stopping on the treadmill to be comparable to or better than what they do during over-ground walking.

3.2 Perspectives on the Treadmill when using the RSCA

The perspectives on the experience of walking on the treadmill using the RTSCA were determined through the participants' responses to 9 closed-ended questions (Figure 4). In assessing their ability and ease to accelerate from stationary, 9 and 8 participants respectively found that the RTSCA enabled them to do so as or better to what they do during over-ground walking, respectively. Although 3 participants responded that the ease of changing from stationary to normal walking speed worse than over-ground walking, only one participant was unable to maintain it. The perspectives were fairly similar on the ability and ease of using the RTSCA for their slow walking speed. For ease of changing from stationary to fast walking speed, 8 participants found it comparable or better than over-ground walking. In terms of ability to maintain their fastest walking speed, 8 participants responded that it was worse than over-ground walking. Ten participants felt that they stopped comfortably as and better than what they do naturally.

In addition, a specific question was asked whether the participants walked at what they considered to be their fastest walking speed; the results show that the majority of the 13 participants (10) felt that they did not do this.

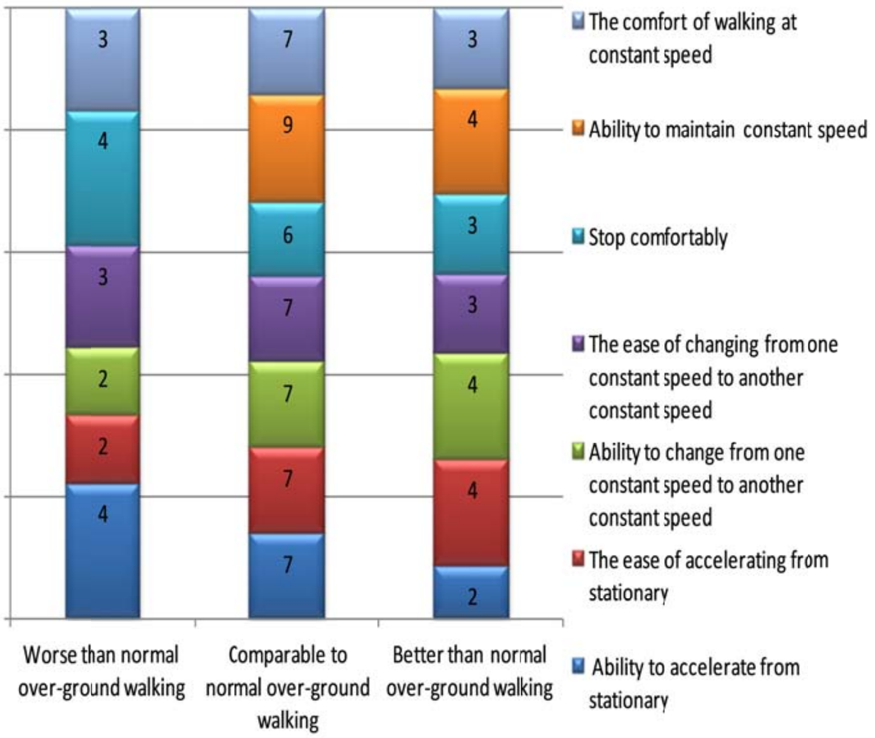

Figure 3. *Responses to questions on the participants' walking experience on the treadmill when using conventional speed buttons. Number in a legend refers to number of responses.*

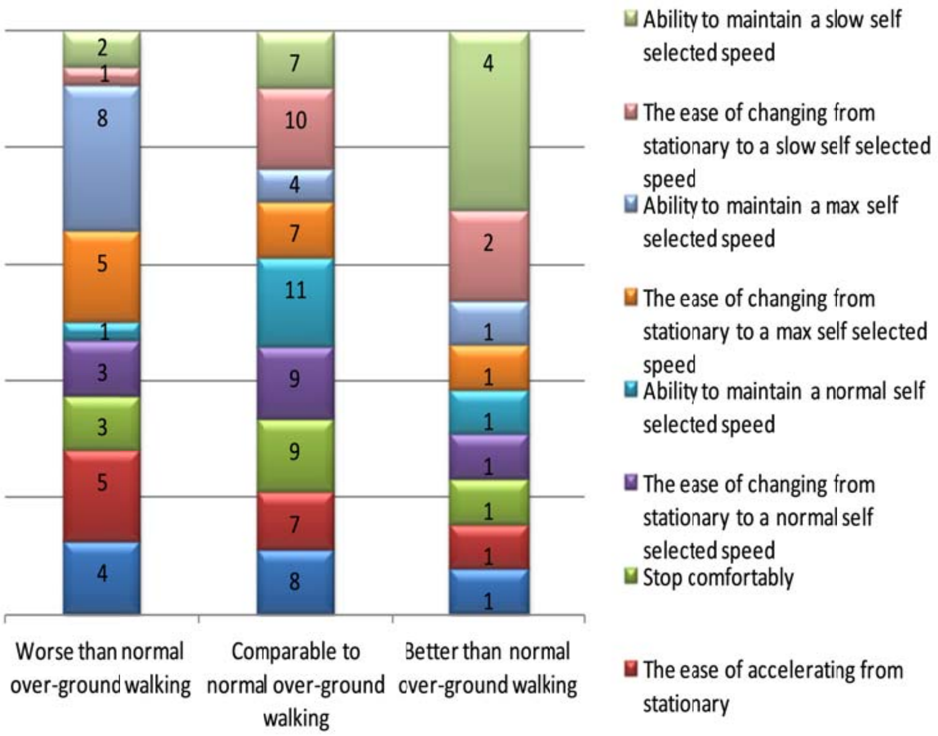

Figure 4. *Responses to questions on the participants' walking experience on the treadmill when using RTSCA. Number in a legend refers to number of responses.*

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In order to explore perspectives on walking on the treadmill when using its speed control algorithm compared to its conventional speed buttons, two general questions were asked (see Figure 5). Ten participants reported that their ability to maintain and ease to change walking speeds from stationary when using the RTSCA was better and comparable to the use of conventional speed buttons.

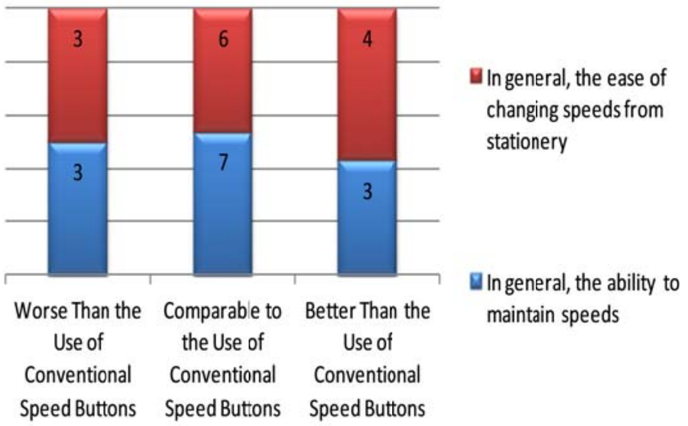

Figure 5. *Responses to general questions on the participants' walking experience on the treadmill when using the RTSCA compared to the use of its conventional speed buttons. Number in a legend refers to number of responses.*

3.3 Perspectives on the Treadmill when using the RTSCA with Virtual City

To explore the performance of the RTSCA when it was incorporated with a VR environment, three closed-ended questions were asked. As can be seen in Figure 6, all the participants were content with the interaction between the virtual environment (virtual city) and the treadmill when using the RTSCA. In terms of how easy it was to use the RTSCA to change between walking speed in order to walk across the virtual city, 11 participants agreed or strongly agreed. Nine participants considered that incorporating the virtual city with the treadmill encouraged them to use the RTSCA. For the open-ended question asking participants for any further comments, 11 participants responded. All of these responses were very positive, apart from a general comment of not being able to walk at fastest possible speed with the RTSCA. For example, a participant stated that "*I felt that I could walk faster but the system did not give more speed*" another participant also stated that "*I did not reach my fast speed at the end of the treadmill*". Comments also suggested that a few participants felt that they did not practise enough with the RTSCA before the testing. A participant stated that "*I think I was not right when I said that I got enough practising of how to use the proposed approach, however, the experience of using this approach was really great*".

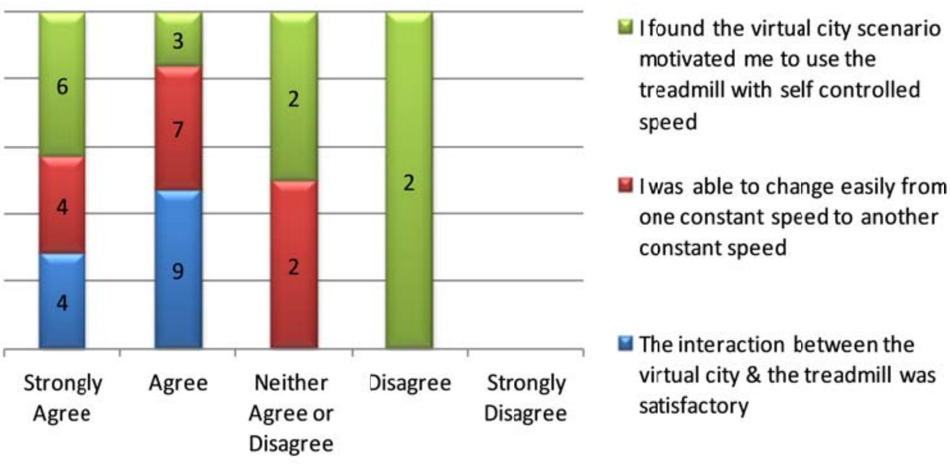

Figure 6. *Responses to questions on crossing the virtual city experience when using the RTSCA. Number in a legend refers to number of responses.*

3.4 Treadmill Speeds

Table 2 shows statistical results for walking speeds with the RTSCA and speed buttons. The mean self-selected normal walking speed of participants increased by 0.21 m/s when using RTSCA compared to treadmill speed control buttons. Similarly, the mean self-selected slow walking speed increased by 0.18 m/s with the RTSCA. In contrast, the mean self-selected fast walking speed only differed by 0.01 m/s. The mean fluctuation for each speed when using the RTSCA was less than 0.015 m/s. A Wilcoxon signed-rank test was performed to examine the hypothesis (H3), with set significance level at $p \leq 0.05$.

Table 2. *Analysis of walking speeds average under the RTSCA and the treadmill speed buttons. St dev: Standard Deviation.*

	Speed Buttons		**RTSCA**		**Fluctuation**		**Wilcoxon test**	
	Mean (m/s)	St dev (m/s)	Mean (m/s)	St dev (m/s)	Mean (m/s)	St dev (m/s)	z-value	p-value (2-tailed)
Normal walking speed	1.06	0.15	1.27	0.09	0.009	0.003	-2.98	0.003
Slow walking speed	0.76	0.10	0.94	0.10	0.013	0.004	-3.18	0.001
Fast walking speed	1.74	0.11	1.75	0.06	0.01	0.003	-0.275	0.783

4. DISCUSSION AND CONCLUSIONS

This paper discussed the overall performance of the proposed augmented speed control treadmill technique as perceived by healthy young adults. The majority of the participants found walking on the treadmill when using the RTSCA similar or more comfortable to using the conventional speed buttons. One key element of this investigation was to observe the safety of using the RTSCA. During the experiment, there were no accident or negative comments about the safety of RTSCA with and without VR. As part of its safety and performance, interestingly, the participants did not notice any possible delay between their walking speeds on the treadmill and the VR speed, which suggests that the RTSCA enabled participants to walk on the treadmill at different speeds smoothly and without noticeable changes in the treadmill speed. The results outlined in this paper indicate that the majority of the participants were content from VR environment and the RTSCA when incorporated with that scenario. Together, these results suggest that the first hypothesis can be accepted and the second rejected. Statistical results illustrate the standard deviation of all speeds under the RTSCA were lower or equal to those under the speed buttons. This indicates that the RTSCA enabled the participants to walk with consistent speeds at least as comparable to those when using the speed buttons.

The results of the statistical test indicate that the H3 has been rejected for the normal and slow walking speeds (p value<0.05), but it has been accepted for the fast walking speed (p value>0.05). Feedback provided by participants on the ability to walk at the fast speed was an interesting response given that the fast speed reached by all participants when using the RTSCA was almost equal to their fast walking speed that was recorded during their use of the treadmill speed buttons. A similar conclusion to this were recorded by Lichtenstein *et al* [2007]. In their study, they reported that subjects showed slower speeds on a treadmill when using a self-propelled (conventional) mode compared to the use of a controlled mode. A limitation of this study is that the walking speeds of the participants in over-ground were not recorded. Therefore, future research should consider this in order to ensure that the RTSCA does not prevent users from walking at their natural speeds.

Whilst positive feedback on the use of the RTSCA was provided by participants, there were comments about insufficient practise prior to using the RTSCA. This will be addressed in future work. For the purpose of our research, the results of this pilot investigation have encouraged us to proceed to a clinical study in which children with CP will walk on the treadmill following the procedure outlined in this paper. Ongoing research will also explore the replacement of the motion capture system by a low-cost markerless system, e.g. Microsoft Kinect for the Xbox 360, allowing the ideas discussed to be more easily implemented in the clinical setting.

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Mathematical literacy for everyone using arithmetic games

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ABSTRACT

An innovative mathematics game shown to be effective for low-achieving mainstream students is tested in special education for learners with intellectual disabilities. The game relies on a graphical, intuitive representation for numbers and arithmetic operations to foster conceptual understanding and numbers sense, and provides a set of 2-player games to develop strategic thinking and reasoning skills. The game runs on computers and interactive white boards, and as an augmented reality application at a science centre. We compare its use in special education and mainstream education with respect to usage, performance levels and learning gain. The game has been used by teachers in special educations, with gains in mathematical understanding, strategic thinking and communication skills as effects.

1. INTRODUCTION

Mathematical literacy is crucial for handling everyday life situations, such as being on time, paying bills, using maps, reading time tables, and comprehending expiry dates (Gregoire & Desoete, 2009). For students with severe learning disabilities the world of numbers may never become accessible, as repeatedly trying to solve problems without an understanding of the underlying concepts creates passive learners and often also results in learned helplessness (Miller & Mercer, 1997). The impact of mathematical skills on employment prospects is even bigger than the influence of poor reading skills (Dowker, 2005). Years of failure in mathematics, can seriously handicap daily adult life (Garnett, 1998). Yet, research on mathematical disabilities is still comparatively scarce (Gregoire & Desoete, 2009).

Research suggests that a mathematical curriculum for students with learning disabilities should focus on "big ideas": a few important concepts (e.g., basic arithmetic) should be taught to mastery rather than numerous skills superficially (Gersten & Chard, 1999). Still, these authors claim, special education instruction continues to focus on computation, in particular exact arithmetic calculations (Rousselle & Noël, 2008) rather than mathematical understanding and estimation. For special education, the following practices are recommended: encourage and practice to "talk math" (Garnett, 1998); use motivational practices such as games (Garnett, 1998); use board-games and other (physical) manipulatives and instructional software (Lock, 1997). Recommendations that, a decade later, were still valid (Evans, 2007).

Our instructional software, a card- and board game, targets conceptual understanding in arithmetic, such as the meaning of addition, and higher-order cognitive skills, such as reasoning and strategic thinking. Students are encouraged to discuss the game (i.e., talk math) while trying to choose good cards. The game is designed to serve as an alternative for students with mathematical difficulties or intellectual disabilities (Pareto, 2005) but as a challenging and useful complement in mainstream education. In other words, it follows a universal design approach rather than an assistive technology approach (Shneiderman, 2000). The game has proved effective for improving students' conceptual understanding in basic arithmetic, and for promoting better self-efficacy beliefs in mainstream education, with the strongest effect for low-achieving students (Pareto et al, 2011). The game has also been used in special math classes within the standard Swedish curriculum, where students receive additional support by special teachers (Nilsson & Pareto, 2010).

In this study, we investigate whether the game can be used effectively also in special education. We are interested in whether its usage in this context differs from that of mainstream classroom use, and whether game-play behaviour, game performance and learner progress differ between the two user groups. We also investigate whether an augmented reality version of the game, enhances game experience and learning.

2. SPECIAL EDUCATION LEARNERS AND MATHEMATICS

Special education for students unable to follow mainstream curricula due to developmental disabilities or permanent brain injuries has existed since 1968 in Sweden. Today, the special education school is a 9-year mandatory school (just as the standard school) with a special, reduced curriculum. Reasons for attending special education include various intellectual disabilities and also severe ADHD and autism. The Special Education includes curricula for students with mild disabilities (normally defined as an IQ below 70), and *training school* for students with moderate or severe disabilities (IQ below 50). However, the IQ level is not the only factor determining if a student is entitled to special education: prior to enrolment, a thorough individual investigation of the student's psychological, social, pedagogical and medical ability to follow the standard curricula is conducted, and consent is sought by the parents.

A national organization, The Swedish Agency of Special Needs Education, has the aim to ensure that children, young people and adults with disabilities will be able to develop and receive an education based on equality, participation, accessibility and companionship. Such view originates from Vygotsky (1978), who argued that the main objective in the field of special education should be the creation of what he called a "positive differential approach", that is, the identification of a disabled child from the point of strength rather than a disability. He suggested for example to measure the level of overall independence in children with mental retardation, rather than the degree of feeblemindedness, which is adopted today. Gindis (1995) argues that Vygotsky's view is the most comprehensive, inclusive and humane practice of special education in the 21st century. In Sweden, the ambition is to have an inclusive school and integrate special education students in standard classes as much as possible, but this is obviously not a reasonable solution for all students.

Intellectual disability is a broad concept encompassing various intellectual deficits, including mental retardation (MR), various specific conditions such as specific learning disability, and problems acquired later in life through acquired brain injuries. Since we study mathematics education, we will go into specific difficulties related to learning disabilities in mathematics. Munro (2003) has identified the following difficulties: difficulty in using mathematical concepts in oral language, difficulty manipulating concrete material such as enumerating objects, difficulty reading and writing mathematical symbols, difficulty understanding mathematical ideas and relationships, and difficulty performing mathematical operations. The different types of difficulties can occur in isolation or in combination (Munro, 2003).

Arithmetic is the base of mathematics. Counting is the most basic skill in arithmetic, since it relates real world quantities to numbers. There are basic rules that need to be understood to be able to count effectively: things should be counted once; the number of the last counted object is the magnitude; the counting order is irrelevant, which is typically misunderstood (Geary, 1999). Even infants have a direct, intuitive perception of the magnitude of small collections of objects (Butterworth, 2005). Most adult can grasp collections up to 7-8 objects in this direct, intuitive manner. This mental process, referred to as subitization, is quite different from counting. A disability in subitizating means not seeing the "threeness" of three objects, thus even small collections of objects must be counted. Children must also learn to associate the three representations of a number: the symbol "2", the word "two" and the quantity (magnitude) "2". Mapping number words onto the representations of these quantities is a difficult task, which can be especially challenging for children with math disabilities who also experience reading difficulties (Berch, 2005). Many students with disabilities can learn the quantitative aspects of mathematic concepts better than the symbolic counterpart. Studies suggest that the two representations are functionally independent (Munro, 2003), thus should not be addressed together. Our game design takes this into account: if the root of the problem is lack of number-sense, this has to be addressed before any further progress can be made (Ranpura, 2000). Finally, students with learning disabilities have difficulties abstracting principles from experiences (Geary, 1993), so opportunity for extensive and prolonged experience with mathematics is needed.

3. THE EDUCATIONAL ARITHMETIC GAME

It is far from evident how to design a game environment that fosters deep mathematical understanding (Moreno & Meyer, 2005). Our approach is to provide 1) a graphical model simulating arithmetic behaviour; 2) a set of two-player games supporting collaboration and competition; and 3) intelligent, teachable agents which can be taught to play the games.

Our educational game teaches arithmetic, specifically base-ten concepts, including place-value, carrying and borrowing, and estimating sets. Notice that base-ten concepts is a major stumbling block for many elementary school children (Carpenter, Fennema & Romberg, 1993), not only children with learning difficulties. The four arithmetic operations are covered, using negative as well as positive integers. All

mathematical concepts are represented graphically: integers are coloured blocks; arithmetic operations are animated actions involving those blocks. All mathematical rules are built into, and thus ensured, by the model. This allows properties and relations to be discovered and explored by the students, since all possible actions are guaranteed to be mathematically valid. The goal is to learn by proxy of doing and by reasoning and making choices and estimations, which is in stark contrast to performing computations and studying concepts in isolation (Case & Okamoto, 1996).

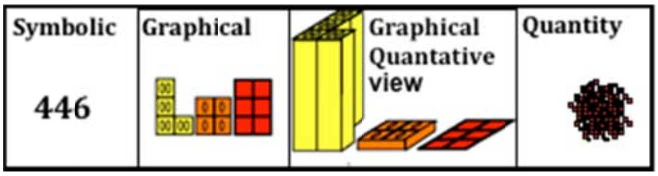

Figure 1. *Graphical representation of integers.*

The graphical representation of integers is coloured blocks and boxes of different heights, as a metaphor for numbers (see Figure 1). Ones are represented as flat red blocks; tens as orange boxes marked with a single zero; hundreds as yellow, taller boxes with two zeros. An orange box contains ten red flat blocks stacked together; a yellow box contains ten stacked orange boxes.

The set of two-player games are based on the graphical model. In these games, players act arithmetic operations using a set of cards. Players take turns, choosing one card, until all cards are played. Although the game, in effect, constitutes a sequence of computations, the task facing the players is not to do the computations but to choose good cards to play according to the game's particular goal, such as maximizing the overall number of carries or the number of zeroes in each turn. Game goals are designed to reveal important properties of arithmetic. For instance, in Figure 2 (top left), the goal is to maximize carries. Here, a card with 6 red blocks is placed above the blue game board already containing 8 red blocks, which mathematically means 8 + 6. This situation occurred since the current player plays addition and just chose the card 6. Now, the computation 8+6 is carried out by the system, following a low-stress algorithm of explicit packing where the blocks from the card are added one by one to the game board until the encircled area is filled with 9 blocks, then the 10th block lands in a "packing area" (the orange arrow illustrating a 10-box above the board) and the 9 blocks on the board are also moved one by one filling the box with ten blocks. When the packing is complete, the orange box falls down in the turquoise 10th-compartment to the right, and the remaining 4 red blocks will now fit, and the computation is completed with the following result: 1 orange ten and 4 red ones, which denotes 14. Such low-stress algorithms can be crucial for learners experiencing difficulties, since they are more explicit, reduce anxiety, and help to conceptual understanding (Lock, 1996).

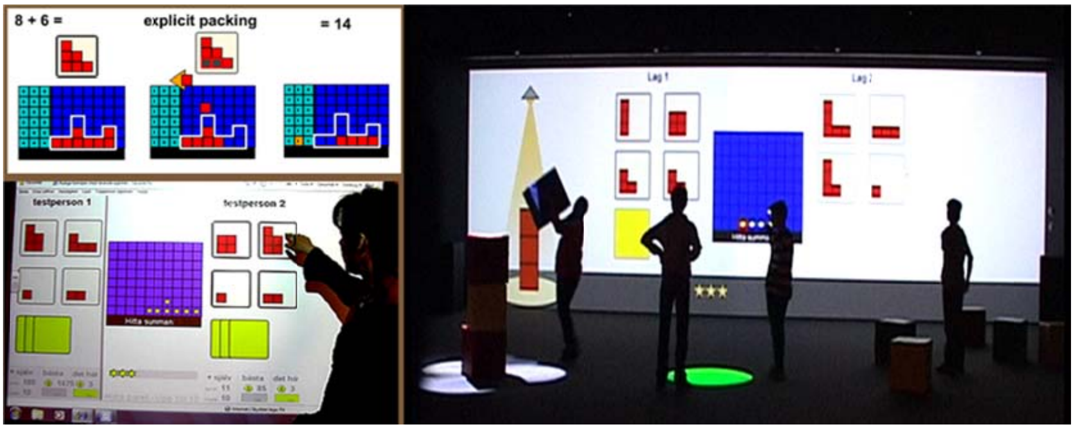

Figure 2. *Explicit carrying operation as packing blocks into boxes (top left), game on interactive white board (bottom left) and game as augmented reality application in science center (right).*

In Figure 2 (bottom left), another game is shown. Here, the goal is to find a pair of cards (one from each player) matching a given goal, in this case the sum 7 (seven stars on the game board that should be filled with red blocks). This game is collaborative and encourages players to reason and discuss alternatives. One solution is to take the card 5 from the right side and 2 from the left, another to take 2 from the right and 5 from the left. The other cards on the right (4 and 1) do not have a matching card fulfilling the goal.

The game currently runs on three platforms: ordinary computers, interactive white boards (Figure 2, bottom left) and an interactive augmented reality 3D-cinema at a regional science centre (Figure 2, right). In

the 3D-cinema, users interact with physical objects connected to a virtual world shown on a 4 meter tall and 12 meter wide scene in 270° wide angle. Here, the study participants 1-4 collaborate by moving physical cubes into a lit-up area to select a corresponding card on the screen. A virtual representation of the 3 cubes is shown on the left of the screen, partly covered by a user carrying the 4th cube towards the light. The cubes contain microchips detected by a sensor and mirrored on the screen; a sensor in the green-lit area detects movements. To select a card with 4 blocks, 4 cubes should be moved to the building area and then someone (or something) must cross the green area.

The game addresses math disability problems in several ways. It provides a constructive, analogical representation, which support understanding the counting principle. The graphical representation of various block-formations encourages different kinds of counting strategies, so that the order-irrelevance principle is explicitly practiced in the model. It also provides opportunity to practice subitization since every digit is represented by a group of blocks proportional to the magnitude. If the magnitude cannot be "seen", the blocks can be counted. For further details see (Pareto, 2005). In the augmented reality version of the game, the sensation of magnitude is further enhanced by having to operationally moving cubes one at a time to experience the sensation that moving 8 cubes are much more cumbersome than moving 2.

Further, the game gives substantial training of causal reasoning, a basic cognitive process that underpin all higher-order activities. (Research on instructional methods for supporting causal reasoning is scarce (Jonassen & Ionas, 2008)). In order to play well, the effect of each card must first be considered, then the alternatives should be valued against each other. The first part requires mental computations or estimations; the second part requires strategic thinking and the ability to reason and judge. Previous research supports our approach: Students with mental retardation can learn to employ cognitive strategies effectively with strategy instruction (Butler et al., 2001). Such strategy instruction promoted not only mathematics performance, but also student independence. Also, other technological innovations (e.g., digitized text combined with scaffolds to assist comprehension) have enabled teachers to provide students with disabilities access to complex concepts and to engage them in higher order thinking (Brownell et al., 2010).

4. THE STUDY

Currently, 7 schools, 60 elementary teachers, and over 900 students in grade 1-8 in a municipality in West Sweden are enrolled in programs financed by the Swedish National School Board or Swedish National Agency for Special Needs. The educations use the game as an educational tool in their regular mathematics lessons, with the objective to improve national standard math comprehension test results. Eight of these students, all enrolled in a Special Education training school, participated in the study. (See Table 1),

Table 1. *Participants in study.*

Special Education students	Class level	Disability	Month played	Strategic game data	Match pair game data	Class room observation	Augmented reality observation	Teacher interview
1	7-8	Intellectual & language	15	X	X		X	X
2	7-8	Intellectual & socially	15	X	X		X	X
3	7-8	Intellectual & language	15	X	X		X	X
4	7-8	Intellectual & language	15	X	X		X	X
5	9	Asperger syndrome	12	X	X		X	X
6	5-6	Down syndrome	4	No data	X	X		
7	5-6	Down syndrome	4	No data	X	X		
8	5-6	Down syndrome	4	No data	X	X		

All the participants except student 5 qualify for training school curriculum, i.e., are judged to have a moderate or severe intellectual disability. Down syndrome is associated with a delay in cognitive ability and physical growth, and a large proportion of individuals with Down syndrome have a severe degree of intellectual disability (Grant at al., 2010). Student 5 is diagnosed with Asperger syndrome, an autism spectrum disorder that is characterized by significant difficulties in social interaction and restricted interests. It differs from other autism spectrum disorders by its relative preservation of linguistic and cognitive development. Atypical use of language is common (McPartland & Klin, 2006).

We engaged the special teachers and their students of training schools in our municipality, who have used the game for the past 2 years. Students 1 to 4 have used the game for the longest time and are still active users. Student 5 used an earlier version of the game two years ago; for him, the main purpose was to practice social and collaborative skills rather than mathematics. Students 6 to 8 have used the game since this spring.

The study included several data sources. *Game playing logs* for all participating students and for about 300 mainstream students in grade 3 to 8 to compare with; in these logs, we can trace playing behaviour and calculate various measures of playing performance and progression. *Qualitative data from observations and interviews*; we have observed the first two game playing sessions for students 6-8, which took place in a classroom setting; these observations focused on teachers' and students' behaviour and interactions during play, and were documented in detail. *Notes from a reflection session* with a teacher. *Recordings* from a first test of the augmented reality version of the game in a science centre, where students 1-4 participated as players and student 5 as tutor: a video recorded from from the back to capture the screen and overall interactions and from the front-corner to catch facial expressions and gestures; a separate recording of the players' speech, using individual microphones in order to capture all communication. *Interviews* with two teachers of students 1-5 concerning 1) the students' ability profiles in general and their mathematical level before starting with the game, 2) the teachers' assessment of individual progressions, and 3) their perception of learning benefits advocated to the game; this 2-hour interview was recorded and transcribed. Unfortunately, the semester ended before we had time to interview the teachers of students 6-8 and to bring these students to the science centre.

5. RESULTS

5.1 *Student ability profiles before play according to teachers' assessments (from teacher interviews)*

Student 1 has an unusual disease affecting his language (talk is slurred) and his fine motor skills (which are poor). At the beginning of the study, he was enrolled in the 7th grade, but should have been 8th grader according to age. His mathematical ability was higher than that of his classmates (student 2-4): he could perform simple computations (which his classmates could not). He did however not understand what he was doing, and did not even pass national tests for grade 3. *Student 2* has a mental age of about 3, and his knowledge level is accordingly very low for grade 7, as he has problems with number sense up to 10. He can communicate well, but seeks and needs the support of adults for many activities. *Student 3* has severe stuttering problems, so communication is hard. He could read simple texts, perform simple addition and subtraction but he had no numbers sense so procedures were performed mechanically with lack of understanding. *Student 4* is at a very low intellectual level. He is bi-lingual but cannot read or write, and a year ago he used only a few words in either language. He managed to point and count physical objects, but could not perform computations like 1+3. He had no number sense and his self-efficacy was extremely low. *Student 5* participates for social skills training by using this collaborative mathematical game. When he started this program he refused to communicate with anyone or participate in any learning activity; he had no tolerance of or empathy for peers less intellectually competent than himself. In the beginning of playing, he voluntarily initiated a discussion with a peer for the first time ever in a classroom situation.

5.2 *Performance data from the Match-Pair games*

All participants except student 5 played the rather newly developed Match-Pair games.

In figure 3, we can see the performance levels of how many of the matching pairs that players in a particular grade have found in average in the mainstream condition, compared to the performance levels of each of our participants. All included students have played at least 20 rounds. The performance measure is percentage found pairs as visualized by the bars. The four measured games are shown in groups on the y-axis. All games have the same goal in each round to find two matching cards, one from each player, that together make a given sum or difference. The games only differ in number range: from the numbers range 1-10, to the numbers range 1-20 where carrying and borrowing are involved, to the range 1-100, and finally to the range -10 to 10 where both positive and negative integers are involved in the sums and differences.

The first 5 bars denote mainstream students in 1st to 5th grade; the middle 4 red, striped bars denote study participant in grade 7-8, and the last yellow, dotted bars denote participants in grade 5-6 (who only played leftmost, simplest game). We can see that student 1 is performing better in more challenging games, and performs at the same level or above 5th graders. Student 2 and 4 only played the match-pair games up to 20, but in these games, they perform better than the average 5th grader. Student 3 performs better than the average 5th grader on the games involving positive integers in range up to 100, but not on the game involving negative integers.

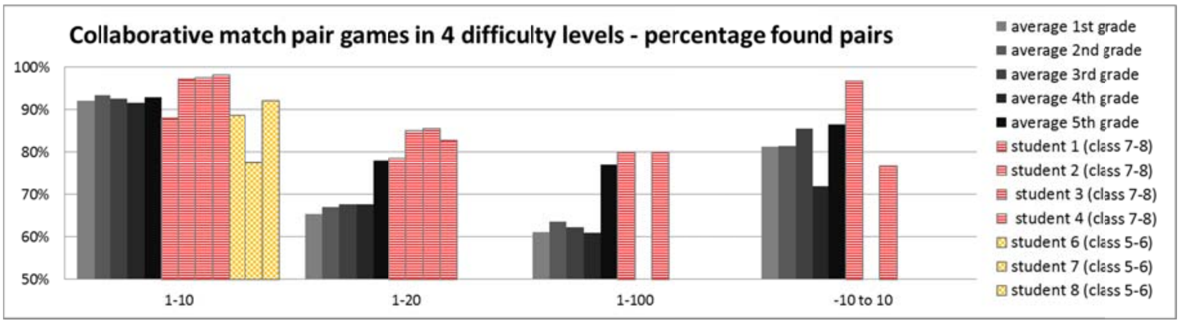

Figure 3. *Performance data from Match-Pair game comparing mainstream and special education students*

5.3 Behaviour data from 2 classroom observations

The two first lessons with the easiest game Match-Pair 1-10 for student 6 to 8 have also been observed. The first lesson proceeded as follows: the three students were placed on chairs in front of the interactive white board, where the teacher and an assistant showed the game several rounds. They emphasized the game idea by making strong gestures accompanying the flashing star (scoring feedback), and showed great enthusiasm and joy. After some rounds, they asked the students to suggest cards to play in order to involve them further. Student 6 and 7 grasped the idea and did suggest matching cards quite often. However, when these two students played themselves shortly after, student 7 where not anymore as confident in choosing, and after some mistakes she refused to play more. Student 6 and 8 played instead, and after some time student 8 also managed to choose a matching card from time to time, and they ended up finding 7 of 10 pairs in their best round. However the idea of collaborating was perhaps the most difficult aspect of the game, and student 6 continued exclaiming "*I won*" every time they received a star despite being corrected to "*the two of you got a star*" by the teacher. In a short reflection session afterwards, the teacher commented that collaborating is difficult for these students, so she was pleased they could practice that in the game. She also explained that student 7 usually wanted to succeed so badly that she refused to do activities where this was jeopardized.

In session 2, the setup was the same. Student 6 and 8 first played together, then each student played the teacher or assistant. Student 7 still refused to play herself, but did participate somewhat from her chair. The players have grasped the mathematical part well, and received high scores most of the time. They were engaged and happy while playing and to the teacher's surprise the students were able to concentrate 10 minutes beyond the scheduled time. Student 8 concluded the lesson with "*This was a good game*".

5.4 Behaviour data from the augmented reality prototype test observation in the science centre

The study participants 1-5 were the first to test the new version of the game in the science centre's augmented reality cinema. The ported game is the same Match-Pair 1-10 as on the other platforms, but where cards are chosen by moving cubes (recall Figure 2, right picture). If there is a card with the same number of blocks as cubes in the building area, then the card is played and the turn goes to the other player. If there are no cards matching the cubes, nothing happened for now (error feedback will be provided but that part was not finished for this first test) and this gave rise to some confusion, but also to some moments for reflection. Students 1-4 tested the game as players, and student 5 as tutor helping the others to play the game.

First student 2 and 4 played. The tutor guided them a little bit, but rather soon they understood the idea. Student 4 takes many initiatives, and is clearly collaborating with his partner, asking "*Where should I put them*" and "*Which should I take, the 3*"? Student 2 takes the lead and is receiving some help from the tutor student, e.g. when the goal is 6 student 2 says "*I take 3 and he takes 3*" (which is properly calculated, but there is no card with 3 blocks among his alternatives). The tutor responds "*You don't have a card with 3, you must take the card with 4*". The game proceeds and soon the two players make their choices without guidance. Student 4 evidently enjoys playing; he walks around smiling and singing while moving the cubes. Then student 1 and 3 continues, and since they already watched a game they know pretty much how to do. Student 3 moved most of the cubes, while student 1 mainly handled the green light selections.

Finally all four students were playing together in pairs, without the tutor. The first goal is 4.

Student 4 moves 2 cubes before the others even are ready to play.
Student 4: "*2+2*" and tries to select the 2 cubes (but there is no corresponding card).
Student 4: "*It doesn't work, I can take 3…* " (and moves one more cube into the area).
Student 4: *Now it works*" (the card 3 is selected).
Student 3 moves 1 cube into the building area.
Student 1 selects and they receive one star.

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The next goal is also 4.

Student 4: *“take 3 again*”.
Student 1: *“no, no, no, don’t*”
Student 4: *“why?”*
Student 1: *“Doesn’t work he has no 3, has no 2, must take 1”* (explains why not any combination will do)

The next turn, student 4 seems to have understood and regains the initiative. The goal is 8.

Student 4: *“I know! I can!*” (and puts the first 3 cubes in the area)
Student 2: *“Hey, I never get to help*”
Student 4: *“Hallo, here take!*” (and gives the 4th cube to his play mate to build on top of the others)
Student 1: *“Take 4!”* (he is directing his team mate)
Student 3 builds 4 cubes on their side
Student 4: *“Now [name of student 1]”* meaning that he should select the 4.
Student 1 selects the 4 and they receive another star.

The game was finished and most matching pairs found.

5.5 Progression data from strategic games

Students 1-5 also played some strategic games, which are more advanced than the Match-Pair games since in these game several choices can yield equal score *this* turn, but be more less strategically good either to block the opponent (if competing) or help the partner (if collaborating) *next* turn. Hence, it is not enough to consider one-step ahead, but several in order to play very well. Progression data for participants 1-5 was extracted from the game log. In figure 4, we can see calculated trend lines of “goodness values” from two different strategic games. A goodness value denotes how good a card choice *is compared to the alternatives* including strategic value, i.e. it measures how good the player performs in a given situation, irrespective of how good the cards are or the other player’s performance. Here, we are mainly interested in trend lines, which is a measure of a player’s *in-game progression* i.e., whether a player improves their strategic game play over time or not.

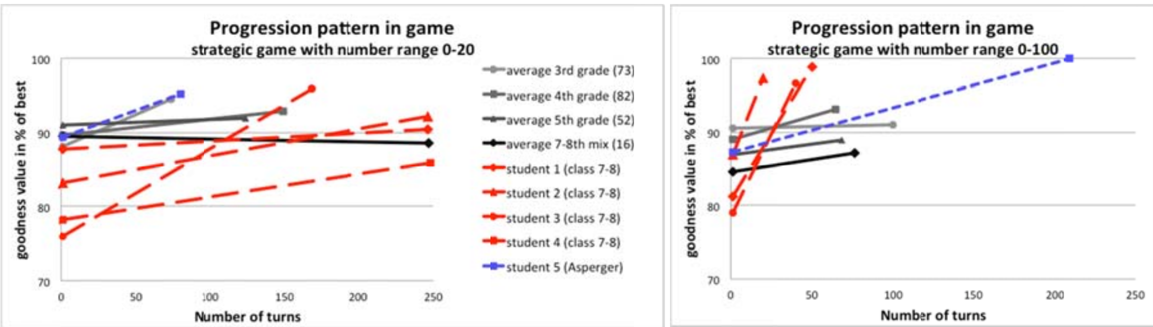

Figure 4. *Progression data from strategic games comparing mainstream and special education students.* The unbroken grey trend lines denote the average trends for 73 3rd graders, 82 4th graders, 52 5th graders and 16 7-8th graders respectively in the two graphs. The red dashed lines are study participants 1-4, and the blue dotted line is the student 5. The y-axis denotes number of turns totally played in the game, so in the left graph the 7-8th graders and student 1, 2 and 4 played about 250 turns, whereas the 3rd graders and student 5 only played about 75 turns in average. Student 3, who started lowest at 76 and ended at 96, made the greatest improvement. The 3rd graders and student 5 also made good progressions ending up at 95 in fewer turns since they started at a higher level. Student 1 improves in the same rate as the 4th graders, but start out a bit lower. Student 2 and 4, who are playing partners, improved at the same quite good rate but at different levels. As a comparison, a goodness value of 97-98 means excellent game play (which is hard for any human) whereas random choice (i.e., only guessing) will yield a goodness value of almost 70. Hence student 3 and 5 reached a very good level of their strategic game play at the simplest games with number range 0-20.

The rightmost trend graph shows a similar but more difficult game in number range 1-100. Here, only student 5 played much, he had an improvement rate similar to the simpler game, and theoretically finished at perfect play (goodness 100). The other study participants only played 20-30 turns each, which means that the trend lines are not very reliable but they indicate greater improvements than the mainstream trends here too.

5.6 Teachers’ assessments of student 1-5 progressions (from teacher interview)

The first 8 months of game play students1- 4 mainly played the strategic games up to 10 (the Match-Pair games were not yet designed then), often competitively. There were not much communication and

discussions. Student 1 and 3 got very engaged when they learned about the teachable agent, and that was when they started to talk during game play and they even wanted to play at home. When the new collaborative Match-Pair games arrived, the focus turned to these games for communication purposes. In the beginning the students simply were not able to collaborate; they refused to look at each other or at the board, and selected cards blindly. The teachers forced them to talk and to look, and the more they succeeded, the better they played. "*Student 4 is the one who gained most in communication skills, the improvement is just amazing*". Today, he can stand in front of the white board and reason about the solution: "*You can take 7, and I will take 2*".

"The game is the reason [student 4] is able to do math, and has gained self-confidence. [Student 2] now knows the numbers up to 10, and has also gained self-confidence, which in turn gives some self-respect. Hence they talk since they are worth listening to. The game was not popular in the beginning. Today when we mention the game, they smile. Every Thursday they play. They really have a hard time learning, but the game has been fantastic for each of these 4 students."

Student 3 gave evidence of a reflective and advanced thought a week after the science centre visit. He asked the teacher "*How could the screen know how many cubes I had placed there?*". The teacher replied that it had to be the proper number of cubes, and the response made him angry because of course he knew that but he wanted to know how it worked and how this was possible at all [technically]. The teacher didn't know the answer to that question, but was very pleased of the student's advanced thought.

"I [the SE teacher] think that these students' low abilities is about having failed so many times so there is no self-confidence left at all. Grouping such students together is not good; there is normally no growth in such a group. Playing this game is an exception when growth actually occurs."

The challenge for student 5 was to act as a tutor, i.e., to scaffold the other students to some mathematical understanding. He managed this beyond the teachers' expectations, for instance asking "*Are you sure or should you look at the cards once again?*" instead of telling them they are wrong. Afterwards he spontaneously praised them: "*You have done really well today*", and when the other students had left he returned to the teacher and said: "*This was an experience, I thought they were all really stupid all the time, but they do understand something!*" It was the first time the teacher heard him able to, in retrospect, articulate such reflection over other people's behaviour as well as his own judgement of them. This student has developed from a non-communicating individual to a mainstream graduate in only 3 years.

5.7 Benefits advocated to game by the teachers (from teacher interviews)

The teachers brings forward the following properties of the game as particularly beneficial for student with learning disabilities (as cited from the interview): *1) That the mathematics is represented without digits and symbols, because after many year of failures digits and letter are closely connected to negative thoughts and expectations of more failures. 2) That everything is visual and they [the students] see what it is. 3) That they can see the carrying, see the blocks move one by one and see the actual packing when it transforms into a 10-box instead – what an aha-experience! 4) When they see the addition operate, e.g., 4+3 actually becomes 7 blocks, they understand. 5) That negative integers are included from start and that adding two negative numbers is the same as adding two positive. 6) That it is a computer game, with a motivating reward system (the stars). 7) The teachable agent, some students really liked to train the agent and be on the top lists. 8) That it is something else than a math book, and that it is something different to all other quite similar math pedagogy. 9) That it focus on understanding, not computation procedures. As soon as you do not understand, math becomes difficult and boring. For students understanding math, it is their best subject, and for students not understanding math, it is the worst.*

6. DISCUSSIONS AND CONCLUSIONS

The use of the game differs between special- and mainstream education. In special education, the game is used in groups of 3 or 4 students together with one special teacher and sometimes an assistant. Groups are equipped with, and frequently use an interactive white board. The whiteboard is used for all game play, and is essential according to the teachers. The teacher(s) are constantly present and ready to scaffold and guide the students during game play if needed. The situation in which student 5 conducted his game play was different; it was a mixed class of 16 students with 8 from special education and 8 from mainstream class and they used ordinary computers. In mainstream classes, there are normally 20-30 students, one teacher, and depending on the availability of computers they play all at once or in half class, in pairs. If there is a whiteboard, it is mainly used for introducing new games or particular features whereas students play on the computers.

The learning situation differ from mainstream education in the respect that special education teachers seems more influential and more integral to the students' learning processes and therefore more important. Scaffolding and guidance that can be beneficial to mainstream students may be necessary for special education learners in order to progress, as indicated by the frequent and prolonged introductions of new games and features. Studies reveal how effective teaching becomes when engaged teachers use content-rich instruction that is carefully crafted and responsive to students' diverse needs (Brownell et al., 2010). Hence, a combination of dedicated teachers using challenging and motivating instruction methods can empower students with disabilities to reach higher levels of learning.

Regarding mathematical achievements, the results show that student's number-sense can be improved by game play (Student 2 and 4 both point-counted even small quantities at start but showed fluency in identifying numbers up to 10 in the end, for instance when moving the cubes at the science centre). The reason for such improvement may include the frequent practice of number sense during game play (at least 4 cards should be evaluated in each turn) and the approximate nature of discriminating among alternatives, which is known to contribute to conceptual understanding and number sense (Rousselle & Noël, 2008).

The comparison of mainstream versus special student performance data from the Match-Pair games reveals that *in-game performances* of special students were higher (above 5th grade level) than *traditional-math performance* (below 3rd grade level). One reason can be the graphical representation of numbers. According to Kilpatrick et al. (2001) a good representation can assist students in undertaking mental, mathematical computations previously unavailable to them. Another reason can be the recommendation of Evans (2007) to provide strong and explicit links between procedural proficiency (anticipate the effect of a cards) and conceptual understanding (graphical representation) which is present in every choice in the game.

When considering progression in the strategic games, the comparison revealed that the special education students as expected started at lower levels than mainstream students but that they progressed more, so that 4 of 5 students ending levels were comparable to the mainstream students' averages. However, the progression required more game play. Skilled learners quickly develop efficient strategies whereas students with learning difficulties in mathematics often acquire these strategies at a slower rate (Evans, 2007).

In contrast to mainstream students who usually are enthusiastic about new computer games, the special education students were all very reluctant at start. It took time, but once they started to engage, their motivation and engagement seems to be higher than the engagement of mainstream students. Their endurance in watching others play or play the same game over and over again, and their enthusiasm about every star, was apparent during observations. They seem to try harder, and the game logs support this perception. One motivational aspect can be the non-failing learning situation. Another aspect can be that the game provides a stimulating activity (i.e. strategic play and reasoning) at their mathematical level (perhaps only up to 10). Finally, we have seen that acting an expert (i.e. teach the agent) is highly stimulating for many students.

The gain in mathematical self-efficacy demonstrated by student 4 in the science centre compared to the beginning, was radical. The progression from speaking only three words and having to point-count three objects to directing and reasoning with the others during the collaborative game play is an amazing improvement for one year. Student 3 who improved his strategic game play from the lowest level to a very good level made a more silent progression, yet impressive. His engagement and self-efficacy became evident at the science centre, where he built almost everything on one side without hesitation. His question about the augmented reality system is evidence of advanced thinking beyond the teachers' expectations.

Besides the mathematical learning, we have seen gains in communication and collaboration skills, in particular in peer-to-peer collaboration, as evident from the science centre observation. Students 6-8 also improved their collaborative skills during sessions. Acting an empathic tutor, is an achievement for a person with Asperger syndrome, and he judged this day to be the best of all in 9th grade. Other proofs of enjoyment using the game include singing and laughing while playing, wanting to play at home and in school, and engaging more and longer than with other activities.

To conclude, the study showed that our arithmetic game can be used effectively by dedicated teachers in special educations: 3 students showed great learning gains in mathematical understanding, strategic thinking or communication skills, 2 students showed good mathematical learning gains at their respective levels, and 2 students are progressing but have not played long enough yet. The game has failed, so far, to engage one student. The augmented reality version of the game seems promising to further engage and foster deep number sense in students with intellectual disabilities.

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Fitness improved for individuals post-stroke after virtual reality augmented cycling training

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ABSTRACT

A virtual reality (VR) augmented cycling system was developed to address motor control and fitness deficits. In this paper we report on the use of the system to train fitness for individuals (N=4) in the chronic phase post-stroke who were limited community ambulators. Fitness was evaluated using a sub-maximal bicycle ergometer test before and after training. There was a statistically significant 13% (p = .035) improvement in VO_2 (with a range of 6-24.5 %). For these individuals, VR augmented cycling, using their heartrate to set the avatar's speed, fostered training of sufficient duration and intensity to promote fitness.

1. INTRODUCTION

Virtual reality environments for rehabilitation of individuals post-stroke have focused primarily on improving movement, whether of the upper extremity, lower extremity or in the context of mobility and ADL. The most recent Cochrane review that summarized the state of the evidence on virtual reality (VR) for stroke rehabilitation found that upper extremity VR applications were favored when compared to a control condition. (Laver et al. 2011) Lower extremity and mobility studies favored VR but did not reach significance. This in part may be explained by a lack of power, as only a few studies (n=3) were included in the lower extremity and mobility section of the Cochrane review. Alternatively, gait and mobility rehabilitation may require not only motor control training, but also fitness training.

It is well established that individuals post-stroke experience fitness deficits. Aerobic capacity post-stroke is reduced. (Mackay-Lyons and Makrides 2004, Severinsen et al. 2011) In a longitudinal study of individuals post-stroke it was reported that while mean peak Vo_2 (a measure of aerobic capacity) increased from one to six months post-stroke it was only 73% of the capacity measured in sedentary healthy controls. (Mackay-Lyons and Makrides 2004) Similar decreases in cardiorespiratory fitness were found in individuals who are chronic post-stroke. Reduced aerobic capacity is associated with walking limitations. (Courbon et al. 2006, Patterson et al. 2007)

Training to reverse fitness deficits post-stroke has been approached in a variety of ways. These include an 8 week water-based exercise program, (Chu et al. 2004) 10 and 14 week cycling ergometer programs, (Potempa et al. 1995, Lee et al. 2008, Rimmer et al. 2009) walking programs ranging from three to six months, (Macko et al. 1997, Macko et al. 2001) which have used BWSTT for acute (Texeira Da Cunha Filho et al. 2001, Mackay-Lyons and Makrides 2004) as well as chronic post-stroke individuals, (Macko et al. 2005)' (Patterson et al. 2008)' (Jorgensen et al. 2010) progressive adaptive physical activity (Michael et al. 2009) and 19 weeks of community based mobility training. (Pang et al. 2005) The consistent finding is that cardiovascular fitness measured with peak VO_2 can be improved with training. While it is recognized that fitness training is important challenges to engaging in such training include adherence, motivation and access to equipment.

We have developed a virtual reality augmented cycling system to address some of the limitations in fitness training for individuals post-stroke. The system is intended for both motor control and fitness training. The objectives of this project were to determine if 1. heartrate could be used as an input variable to drive the exercise intensity in a the virtual reality augmented cycling system, 2. individuals could train for a long

duration (up to an hour), and if 3. training in the cycling virtual environment (VE) would result in improvements in cardiovascular and pulmonary fitness. We hypothesized that coupling of the VR assets s (Rizzo and Jounghyun Kim 2005) for sound exercise physiology principles would result in fitness benefits.

2. VIRTUAL REALITY AUGMENTED CYCLING

We have designed a virtual reality augmented cycling kit (see Figure 1) to concurrently promote mobility and fitness training. The kit is modular with sensorized pedals and handlebars that control the behavior of the rider in the park-like VE. The kit was designed to convert any bicycle into a virtually augmented cycle. The system is more detail elsewhere. (Ranky et al. 2010, Ranky et al. In Review) There are multiple inputs into the VE including the force generated at the pedals and the heartrate from the polar monitor. In this paper we focus on the heartrate input, however the pedal kinetics which promote riding symmetry are important for the recruitment of the stroke affected lower extremity. The ideal cycling pattern will recruit both lower extremities rather than promoting compensation by having the less affected limb dominate the pattern.

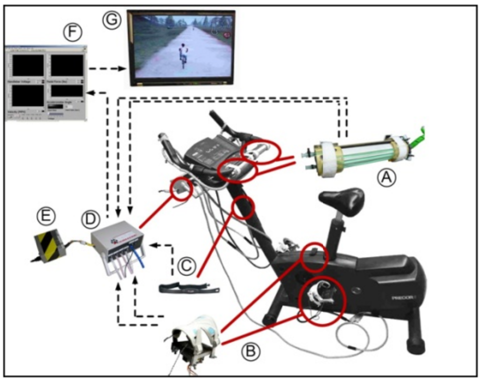

Figure 1. *Virtual Reality Augmented Cycling Kit (VRACK): A: Sensorized handle bars, B: Sensorized pedals, C: Heart Rate sensor and monitor D: Controller E: Power source F: Practitioner interface (where the target heart rate is set) G: Virtual Environment.*

The VE is a riding simulation with two avatars, one for the rider (in red) and the second for the pacer in blue (see Figure 2). The pacer cycles based on a target heart rate (THR) which is set by the therapist, is displayed inside a heart. The rider catches the pacer by working at an intensity that matches their target heart rate. If the rider exceeds the target heart rate the heart beats louder and gets larger indicating that riders need to exert themselves less in order to stay within their safe training range. The VRACK integrates with the bikes functionality. This permits the rider's workload to be adjusted by changing settings on the bike such as the work rate (in watts) and the resistance mode (constant or isokinetic). In this study the VRACK was attached to a biodex recumbent bicycle in which the work rate and resistance mode were adjustable.

Figure 2. *Virtual Environment: Rider in red (insert figure on left) uses exercise intensity based on his measured heartrate to catch the pacer (in blue) who is far ahead. At the start the rider and pacer are together, the rider's trajectory in the VE is displayed in the right upper corner.*

3. METHODS

3.1. Participants

Four individuals in the chronic phase post-stroke (one female and three males; ranging in age from 47 to 65) and one healthy sedentary control (male 48 year old) participated in this study. The individuals post-stroke presented with residual lower extremity (LE) impairments (LE Fugl Meyer scores ranged from 24-26; were house-hold to limited community ambulators (walking speed ranged from .56 to 1.1 m/s); and reported residual walking deficits such as limitations with walking distances. Participants were approved to participate by their primary care physician. One of the participants was engaged in a regular exercise program walking on a treadmill several times a week (S4) and second was swimming several times a week (S3). The other two participants did not have a regular exercise routine (S1 and S2). Participants were asked to maintain their regular exercise activities and not modify them during training.

3.2 Testing

Participants were consented and oriented to the protocol. Characterization of the subjects post-stroke sensorimotor impairment was performed with the lower extremity Fugl Meyer, which is valid and reliable (Duncan et al. 1983, Gladstone et al. 2002) (Sullivan et al. 2011) and related to gait pattern and speed. (Dettmann et al. 1987) Walking speed was collected using three walking trials at self-selected speed over the Gait Rite mat. Validity, reliability and MCID are well established. (Perry et al. 1995, Evans et al. 1997, Richards et al. 1999, Fulk and Echternach 2008) Cycling ergometry testing was used to assess fitness. An exercise pre-testing session using ACSM/YMCA sub-max VO_2 bike stress test was performed. (ACSM Guidelines: 8th Edition). Subjects were instrumented with a polar heart rate monitor and outfitted with a mouthpiece. Testing was conducted using a Cosmed K4B2 metabolic stress testing system. Subjects pedaled at 50 revolutions per minutes (rpm) (paced by a metronome), and reported their rate of perceived exertion (RPE) and exercised until they achieved 75-85% of maximum heart rate or needed to stop the test because of fatigue. Upon completion of training the post-test bike stress test was performed. Two participants reached their maximum heartrate and two participants stopped the test because of leg pain.

3.3 Intervention

Training on the virtual reality augmented cycling system took place over eight weeks. Participants attended two times a week and cycled between 20-30 minutes in the first session with increases until they achieved 60-minute sessions. Recommendations for cardiorespiratory fitness training in individuals post-stroke published by the American Heart Association range from 2-5 days a week for 20-60 minutes a session between 2 and 12- weeks (Gordon et al. 2004). The rate at which subjects increased their training time varied as did their total training time. See Figures 3 and 4. Training intensity was set to between 20 and 30 beats per minute above their resting heart rate. This HR set the pacers' rate in the virtual environment. A variety of features were manipulated in the simulation: path width, complexity and perturbations to increase immersion. The gain was also manipulated to change the rider's pedaling rate. Parameters on the bicycle, as well as on the VRACK, were varied to provide intervals of training that had greater resistance or speed. This was achieved primarily by changing the bicycles workload. The polar monitor tracked heartrate, which was displayed on the practitioner interface. Cycling included a warm and cool down period as well as time in the target heart rate zone. Intervals of cycling with attention to force generation were interleaved during the target heartrate training period. Blood pressure was recorded manually using a sphygmomanometer at ten-minute intervals. Concurrent with heart rate and blood pressure measurements subjects rated their perceived exertion. Exercise progression was based on heart rate response, reports of neuromuscular fatigue and perceived rate of exertion. The workload on the bike was increased as the heart rate response and neuromuscular fatigue tolerated it.

To ensure safety during training HR will be monitored continuously and BP every five minutes. American Congress of Sports Medicine guidelines were followed for exercise responses: a) HR did not exceed target HR; b) BP did not exceed 200/100 during exercise.

3.4 Data Analysis

Training time data were summarized and binned by week and as totals. Metabolic testing data were summarized descriptively. A non-parametric paired t-test with an alpha level of .05 was use to test the hypothesis that training in VR improved aerobic capacity. The dependent variable was sub-maximal VO_2 acquired pre and post the training.

4. RESULTS

All of the participants completed the eight-week training program. There was 100% adherence and no adverse events related to the training program were recorded. With the aid of a binding system at the foot all participants were able to use both lower extremities to bicycle. The virtual reality augmented cycling system accurately read the heart rate parameters throughout the training. Post-stroke participants achieved between 90 and 125 minutes of bicycling each week (see Figure 3) with a total of 800 to 1,000 minutes (see Figure 4) over the total training period. There was not a direct relationship between average training time and changes in aerobic capacity were not significant.

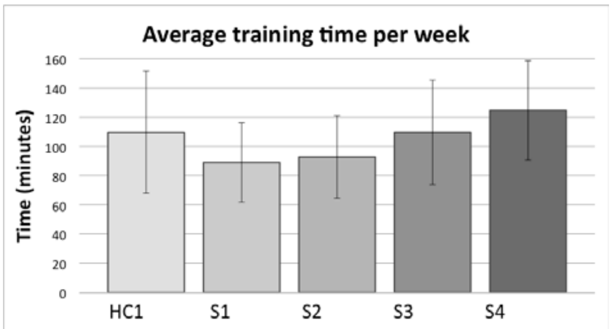

Figure 3. *Average Training Time per week* .

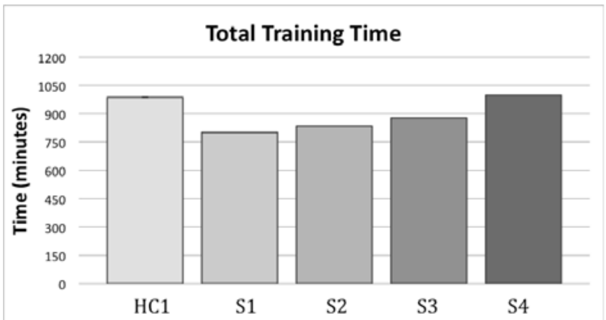

Figure 4. *Total Training Time by Subject.*

All participants post-stroke increased their aerobic capacity as measured by their oxygen consumption. There was a statistically significant 13% ($p = .035$) mean improvement in sub-maximal VO_2 (with a range of 6-24.5 %). Please see table one for a summary of the pre and post training values for time of exercise testing, workload achieved, heart rate, VO_2 and reported rate of perceived exertion. Two individuals post-stroke (S1 and S3) increased their exercise test time and workload, while the other two (S2 and S4) who had the symptom limited exercise test, did change their time and their workload either did not change (S2) or decreased (S4). Two out three out of four subjects did not have a change in their RPE rating. The healthy control also demonstrated an increase in oxygen consumption. Relative to the healthy control the individuals post stroke had lower oxygen consumption both at pre and post-test.

Table 1. *Results of Metabolic Testing Before (Pre) and After (Post) VR training*

Participant	Time (min)		Workload (watts)		HR (bpm)		VO_2		RPE	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
HC1	15	16.4	171	196	149	152	34.6	36.5	13	12
S1	12	14	98	123	167	167	18.3	21.5	14	9
S2	9	9	98	98	119	112	24.1	25.8	15	15
S3	7	11.5	98	123	110	117	19.5	25.8	13	13
S4	12	12	147	118	119	118	17.3	18.5	15	15

HC: Healthy control, S: Stroke, HR heart rate; VO_2: oxygen consumption; RPE: rate of perceived exertion.

5. DISCUSSION

The objectives of the study were met. The VRACK reliable read the user's heart rate as an input into the virtual environment, participants achieved training durations between 40 and 70 minutes per sessions and there was an improvement in aerobic capacity after training. Although not the focus of this paper, there were also kinetic changes of cycling indicative that the stroke affected lower extremity was recruited during the cycling pattern.

Rehabilitation of mobility for individuals post-stroke requires a multi-factorial approach. These factors are sensori-motor, cognitive, perceptual as well as physiological. The ability to incorporate physiologic

variables to drive training intensity can expand the functionality of virtual reality applications for post-stroke rehabilitation. Given the complexity of training in VR it may be difficult to isolate the active ingredient; although this would be a relevant line of inquiry for future studies.

6. CONCLUSIONS

To our knowledge this is the first report to describe improvements in cardiovascular and pulmonary fitness after individuals post-stroke trained in a virtual reality augmented cycling environment. While the early finding is encouraging, it requires replication and extension to rehabilitation of relevant motor behaviors for people post-stroke.

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Haptic presentation of 3D objects in virtual reality for the visually disabled

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ABSTRACT

The paper presents an initial research on haptic perception of 3D objects in a virtual reality environment for aiding the visually disabled persons in learning new routes and obstacle identification. The study spans a number of fields, from the very technical, such as scene segmentation and obstacle detection algorithms to psychological aspects such as the effectiveness in utilizing haptic information. The authors constructed a prototype system for the tactile presentation of real objects in a virtual reality.

1. INTRODUCTION

Research concerning the application of haptic force feedback devices for the blind are worth further development as sight cannot be substituted by the auditory information channel alone. Information concerning the living environment can be complemented in this case by the sense of touch.

Furthermore, designing the tactile system dedicated to people with visual disabilities would allow them to access information from the virtual 3D world simply by touching it. The system should consist of three major elements: a camera (provides information about the distance from obstacles in a scene – a depth map), a computer (the depth map is segmented and the virtual scene is created) and a haptic device (the interface for a tactile presentation of the acquired scene). A haptic device is the interface used for communication between a human and a virtual reality. Thanks to the force feedback it produces, a user can feel the shape, density and texture of 3D objects created in a virtual world. The touching experience when using this interface is quite close to reality. Haptic perception incorporates both kinaesthetic sensing, (i.e. of the position and movement of joints and limbs), and tactile sensing, (i.e. through the skin) (Loomis and Lederman, 1986). The most popular haptic devices available are the Phantom Sensable (Sensable Corp.) and a range of touching manipulators from Force Dimension (Force Dimension Corp.). The systems define one contact point at a time between the observer and the virtual object. They do not stimulate cutaneous receptors responding to temperature, pressure and pain. The mentioned devices have great potential and they were considered for use by the blind to familiarize themselves with obstacles inside buildings and for learning new routes and shapes. However, their high cost limits their availability to the average user. Since haptic force feedback technology has entered the world of computer games, a new low-cost device called Falcon Novint (Novint Corp.) has appeared on the market. Although the device has only 3 degrees of freedom, compared to that of the Phantom Sensable with 6, this is enough for the 3D object presentation. The aim of this experimental study is to present a prototype system which allows for real scenes to automatically appear in a virtual reality (by means of a time-of-flight 3D camera) and to be accessed in the haptic form by the usage of Falcon Novint.

2. RELATED WORK

Research concerning the application of haptic-force-feedback, stationary devices for navigating the blind can be divided into two categories: building virtual maps and creating simulators where real obstacles and objects are presented virtually. They are made for learning new routes and it seems they have the potential as a tool which the blind can use to acquire knowledge about a place for an intended first time visit.

The majority of projects are focused on checking if advanced, expensive devices with a proven quality of performance can be used for such purposes. In the paper (Jansson et al., 1999), two independent studies investigating problems concerning the use of haptic virtual environments for blind people are described. Two

devices, a Phantom 1.5 and an Impulse Engine 3000 were used to render virtual textures and 3D objects. Experiments proved that objects rendered by these devices can be effectively perceived by both blind and blindfolded sighted observers. However, the investigated scenarios were very simple. In another publication (Jansson, 1998), the usefulness of a haptic force feedback device (the PHANToM) for information without visual guidance was also confirmed. The author of the project tried to find the answers to the following questions: how well blind-folded observers' perception of the roughness of real and virtual sandpapers agree and if the 3D forms of virtual objects could be judged accurately and with short exploration times down to a size of 5 mm. Blind-folded sighted observers judged the roughness of real and virtual sandpapers to be nearly the same. The presented experiments were concluded with a statement that a haptic device can present useful information without vision. Considerations using tactile maps for the blind were published. The paper (Kostopoulos et al., 2007) describes a framework of map image analysis and presentation of the semantic information to blind users using alternative modalities (i.e. haptics and audio). The resulting haptic-audio representation of the map is used by the blind for navigation and path planning purposes. However, available literature in the field lacks concrete findings concerning the usage of Falcon Novint game controller.

3. THE PROTOTYPE SYSTEM FOR HAPTIC PRESENTATION OF 3D SCENES

The haptic presentation system was built in order to enable the blind people a touching interaction with 3D real objects created in virtual reality. The prototype consists of an SR3000 camera (Mesa Imaging AG), a laptop and a Falcon Novint haptic interface (see Fig. 1).

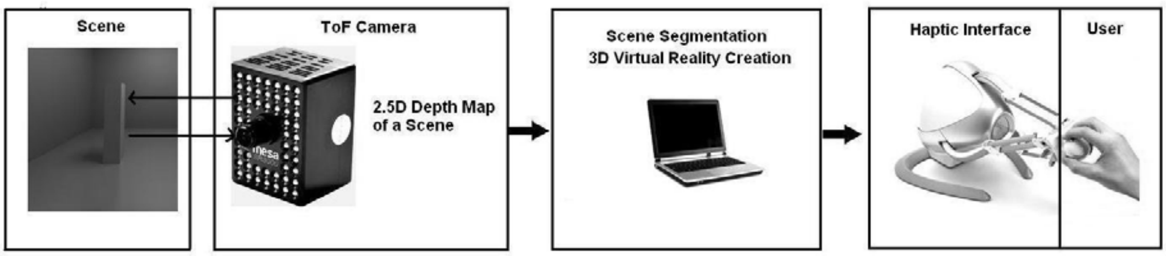

Figure 1. *Diagram of the designed system.*

The camera provides information about the distance from obstacles in a scene by calculating the time of flight of the emitted and reflected back light. A 2.5D depth map is calculated at the output. The camera is connected to the remote computer. Data processing on a laptop is divided into two stages: the scene segmentation and the virtual scene modeling (see Fig. 2).

3.1 Segmentation

On a laptop, the depth map is segmented in order to extract all obstacles from the acquired scene. This process allows gathering information (i.e. location and size of objects) that is used to create a virtual scene.

First, the point cloud representing the scene is processed in order to find points corresponding to planes. Planes finding procedure is based on normal vector estimation at each point. For a given point $p_t(x_0,y_o,z_0)$ with normal vector:

$$\vec{n}\{a,b,c\} \tag{1}$$

the equation of a corresponding plane is given as:

$$a(x-x_0)+b(y-y_0)+c(z-z_0)=0 \tag{2}$$

The input point cloud data is proceed as follows:

- The input point cloud is ordered in a k-d tree data structure (K-D Tree).
- A normal vector at a each point is estimated from the surrounding point neighborhood. For this purpose *k-neighbours* are found. Next, the *k-neighbours* are used to calculate normal vectors (Rusu, 2009).
- Points which have the same normal vectors are grouped together (a certain deviation angle between normal vectors is assumed).

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- RANSAC algorithm (*Random Sample Consensus*) is applied to each group of points in order to find planes (a given group may include a few parallel planes, therefore certain distance threshold between points and the minimal number of points which form a plane are assumed).

The calculated planes are filtered from the input cloud.

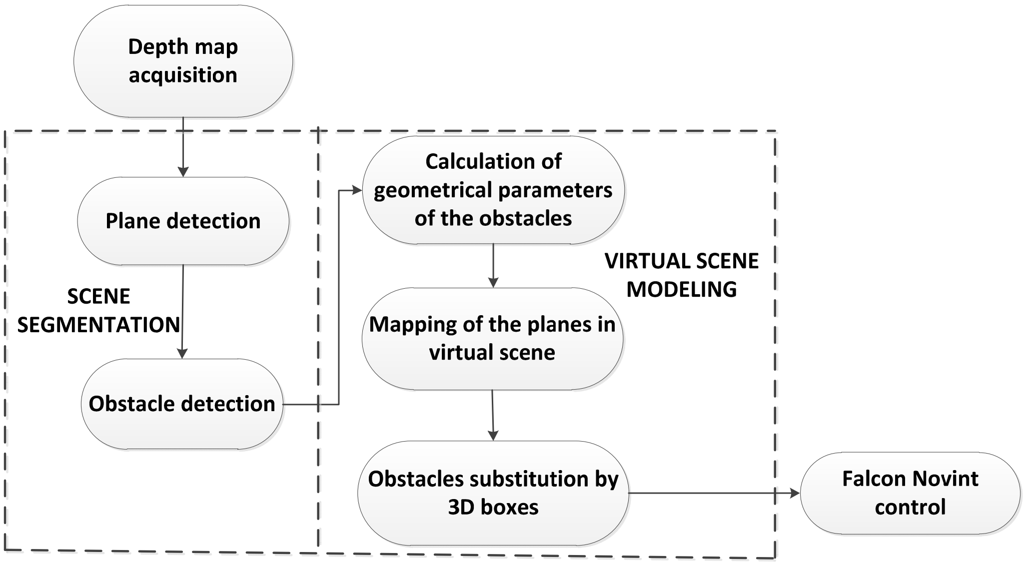


Figure 2. *Diagram of the designed system working principle.*

Next, the clustering algorithm (Rusu, 2009) is used in order to find points representing objects. Two points from the point cloud form an object when the distance d between them is shorter or equal to the assumed distance threshold d_{th}.

3.2 Scene modeling for the tactile presentation

The Falcon Novint haptic game controller is used for presentation of the virtual scenario. Using her/his sense of touch the blind user accesses information about the content of the observed scenes.

The procedure of the virtual scene modeling is as follow:

- The found planes are created in a virtual reality (the background and the ground planes).
- The real obstacles are substituted by 3D boxes whose sizes and locations correspond to the real sizes and locations of objects. Locations of the boxes are given by the centroids calculated for each point cloud representing obstacles. Sizes of the boxes correspond to the maximum distance between points representing obstacles along the X and Y axis.
- The haptic and graphic rendering algorithms are applied to the created scene and the Falcon Novint device is activated. For the purpose of a tactile presentation an open source haptics software development platform H3D is used (H3D API).

Procedure of segmentation and scene modeling are presented in Fig. 3.

4. EXPERIMENTS WITH THE BLIND USERS

Experiments were designed and performed in order to examine usability of the tactile presentation of the real environment in a virtual reality, utilizing the designed prototype system for the blind users (see Fig. 4).

4.1 Aim of research

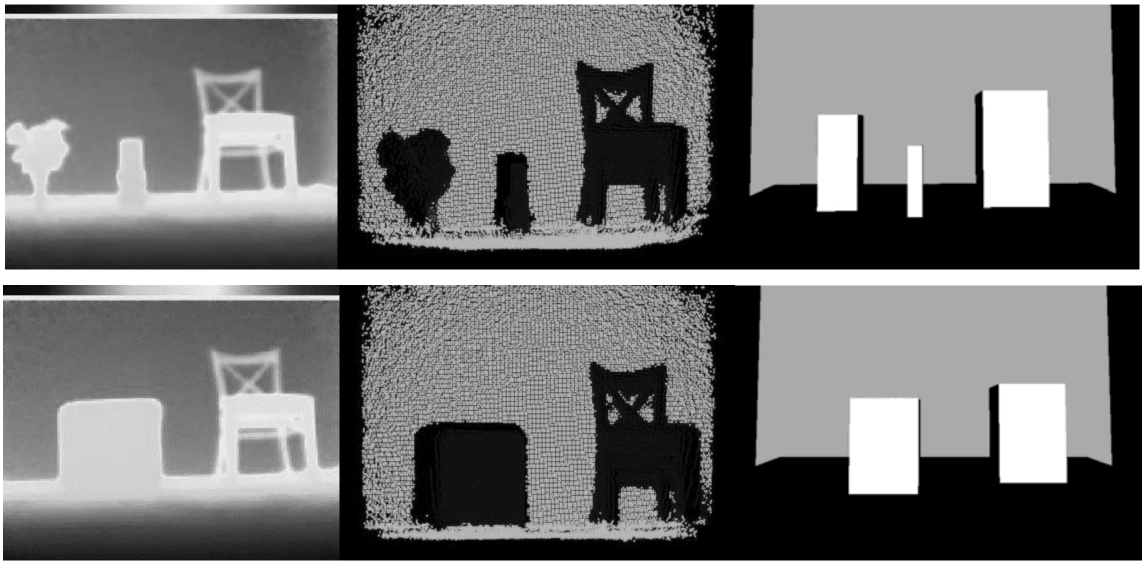
Performed experiments had following goals:

- Check the opportunity of the application of the tactile presentation system for the blind and visually impaired.
- Examine the usability and potential of the force feedback device, Falcon Novint, for a 3D virtual object presentation without the usage of vision.

- collect the blind participants' opinion about their requirements and preferences concerning the design of such a system and learn the potential application areas of it.

4.2 Participants

The group of participants consisted of eight blind people, two women and six men. Six of them were born blind and the others lost their sight at different times during their lives. They were chosen as representatives of different educational and occupational backgrounds. They also represent a different ability of tactile perception of the surrounding environment.



a) b) c)

Figure 3. *The virtual scene modeling process: a 2.5D depth map of the scene a), the segmented scene b) (grey – found planes, black – found obstacles), the reconstructed scene for the tactile presentation c) (the obstacles are replaced by cubes, see the text).*

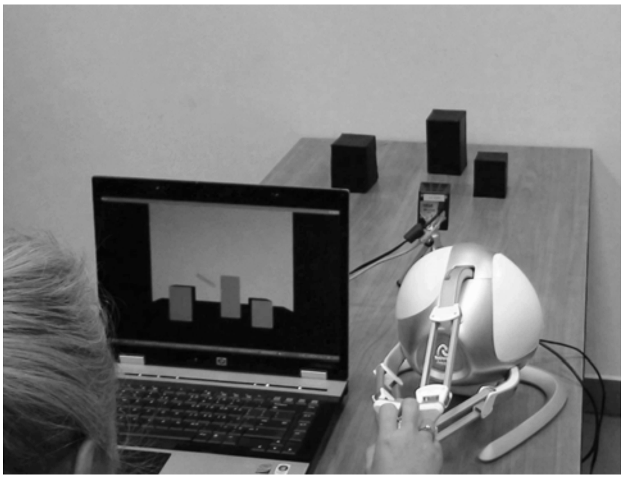


Figure 4. *Prototype system tested by the blind.*

4.3 Procedure and evaluation

The experiments were divided into 4 stages:

- Stage 1 – Training phase

  Participants were informed about the prototype system. Then its functionality was explored. The practice period with the device was adjusted according to the ability of each participant (15-30 minutes).

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- Stage 2 – Scene content recognition

  Experiments were performed for scenes with different number of obstacles (between 2 and 5). Participants were asked to say how many obstacles were presented in each scene.

- Stage 3 – Distance estimation to each obstacle from a chosen point of observation

  This stage was divided into two scenarios. In the first scenario, three scenes with different location of one object were presented. In the second scenario, one scene consisted of 3 objects was presented. In both cases, participants were asked to estimate objects' distances to the chosen point of observation (e.g. the background wall).

- Stage 4 – Estimation of obstacles' height

  Three scenes with different number of objects were presented (between 2 and 5). Users were asked to estimate heights of objects in each scene (the height of an object was estimated in relation to the other objects).

The objects in each scene were located on the ground, against a background wall up to 7.5 m (the SR3000 camera measurement range). Exploration time of every scene was measured. Every participant decided themselves when to finish exploration of a given presented scene. After the exploration was finished he/she was asked to describe the scene. The task was carried out successfully when the blind person correctly identified all obstacles in the presented scene.

4.4 Results

The results of the second stage are presented in Fig. 5 and Fig. 6. The outcomes of the third stage are shown in Fig. 7. The outputs of the last stage are presented in Fig. 8 and Fig. 9.

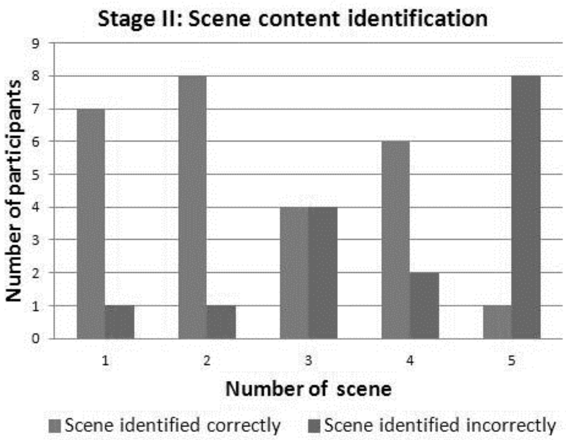

Figure 5. *Results of the second stage of experiments.*

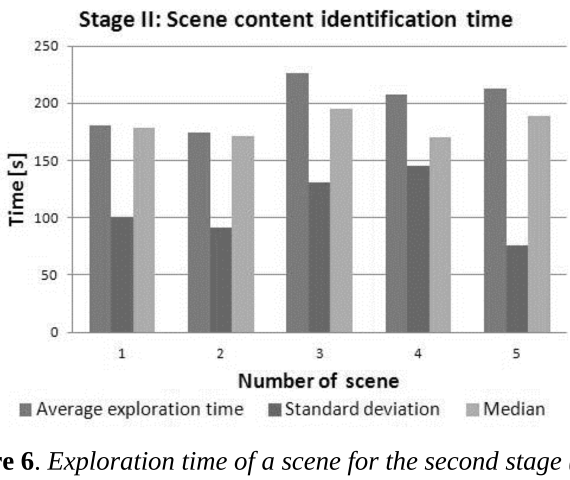

Figure 6. *Exploration time of a scene for the second stage (all users).*

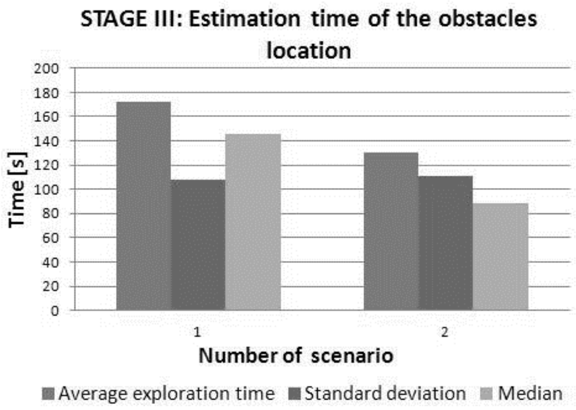

Figure 7. *The outcomes of the third stage of experiments.*

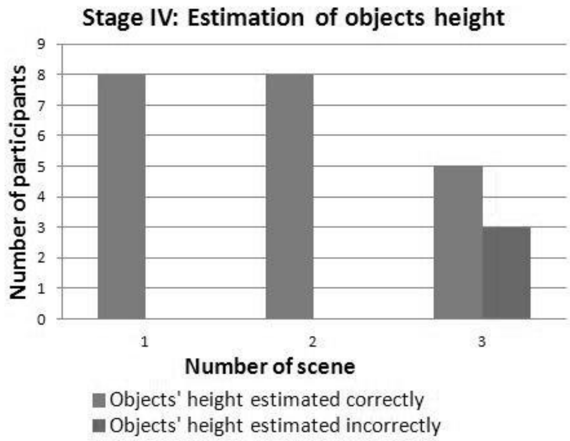

Figure 8. *The results of estitamtion of objects' height.*

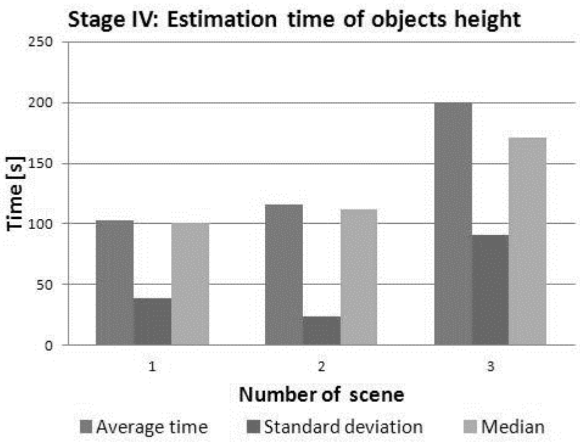

Figure 9. *Exploration time of a scene for the fourth stage.*

4.5 Discussion

Diverse exploration time of the scenes was measured. It depended on a tactile perception skills of the participants and on the chosen way of the scene exploration. The time of exploration was not lengthen proportionally to the complexity of the scenes, because the participants learnt how to efficiently use the haptic interface in order to identify the scene's content. In the second stage the worst result was obtained for the scene with 5 objects (two object were identified as one, because they were located close to each other). In the third stage two ways of the obstacle's location estimation were compared. In both cases participants were able to find location of objects in relation to a chosen point of observation, but in case where all obstacles were located in one scene the process was faster (the distances could be compared directly without switching between scenes). In the last stage for scenes containing two or three objects nobody had problem to properly

estimate the heights of the objects. For the scene with five objects three blind persons failed to correctly recognize objects' heights.

When all the experiments were completed, the blind participants expressed their opinions about the system and its usability in real life scenarios. They were impressed by the system's performance. In their opinion, there are a couple of potential applications where such a system could help the blind in everyday activities. They gave many hints about improving the system. The first suggestion was to add vocal information about the 3D position of the probe (the virtual finger in the system). This would be very helpful in order not to lose themselves in the virtual environment. Furthermore, the sonification of some of the scene points or objects could also be very useful as the volunteers suggested (the presented research concerning the perception of 3D objects by touching it). Special focus is also required when creating virtual objects. They should be as similar to those real ones as possible (size, stiffness, texture, density). When the scene consists of many objects that differ in size, the smaller ones should be created specifically to be noticed.

5. CONCLUSIONS

In the article a prototype system for tactile presentation of real objects in a virtually reality was described. The system usability was examined by the blind participants. The performed experiments have proved that the system can be applied for the blind and emphasized the challenges that yet have to be overcome. This kind of application has to meet special requirements in order to be safe and reliable. The challenging issue is to present a real world scenario in a virtual reality. Many requirements need to be met, mainly: choosing the scale of virtual objects in the ratio to the real ones, solving the problem of losing oneself in VR, solving the problem of presenting scenes consisting of many objects/details (each of a different size), as the system's resolution is finite. The above are all the subject of scientific research in terms of the technical and psychological aspects.

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When sighted people are in the skin of visually impaired ones: perception and actions in virtual reality situation

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ABSTRACT

Most of us do not know how a visually impaired person perceives and acts within the environment in everyday life. In this context, an experimental study was conducted using a virtual reality simulation in which sighted people were immersed in low vision situations: Blurred vision, Tunnel vision, central Scotoma. After a brief familiarization procedure with a virtual reality tool called "SENSIVISE" which includes a virtual apartment, 24 adults had to explore two rooms through low vision simulation or full vision (as control group) to identify their location, and then were instructed to find particular targets. Perception and actions performances were measured in terms of time needed to answer questions related to visual perception, and distances between the participants' body and the screen. The results show that low vision simulation impairs perception among sighted people. It was expressed by a statistically significant effect of lower times needed to execute tasks compared to the control condition. Consequently, the sighted individuals realized how it is difficult to perceive and move when vision is limited.

1. INTRODUCTION

According to the World Health Organization, visual impairment affects nearly 246 million worldwide, including 1.7 million in France with congenital or late visual deficiency (Sander et al, 2005). With an aging population, the number of visually impaired people is growing rapidly due to multiple visual affections such as age related macular degeneration (AMD). AMD often results in vision loss to the central 15–20 deg. of the visual field (i.e. central Scotoma), and frequently afflicts both eyes (Cheung & Legge, 2005). Peripheral field loss (Tunnel vision) is a severe constriction of the peripheral field leaving only the central 5-10 deg. of the field functional. These forms can present varying degrees, in which the available visual field (central vs. peripheral visual-field loss), residual visual acuity, level of contrast sensitivity are all factors that play a role in influencing cognitive performance (Merabet et al., 2005) and behavior in daily life. For example, AMD is associated with decreased quality of life (Brown et al., 2002) and depression (Rovner & Casten, 2002).

When visually impaired people cannot control their daily interactions with the surrounding world, rupture with the family, social and professional networks, will operate. If we know that visually impaired persons are unable to watch the television from a normal viewing distance due to their Blurred vision, the most important information about their difficulties and needs are still misunderstood. And therefore, providing them assistance represents a challenge to family or sighted individuals who may lack knowledge about their relative's visual impairment and the impact of visual acuity and central or peripheral vision on functional abilities. But this lack of knowledge leads the family members to overprotection (Ponchillia, 1984).

Otherwise, when family members include vision impairment, the independence feeling of their visually impaired relatives is enhanced (Cimarolli and Boerner, 2005). In addition, studies on teachers' attitudes towards students with disabilities showed a significant impact on the educational experience (Kenny and Shevlin, 2004).

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The use of Virtual Reality (VR) for rehabilitation and learning in the public health domain had already given positive results (Rizzo et al, 1998; Klinger et al, 2010), notably in the field of visual impairment (Lahav, 2006; Sanchez and Zuniga, 2006). VR has also been used to enhance awareness of educators or caregivers about difficulties met by people with disabilities in daily life (Pivik et al, 2002; Klinger et al, 2007; Passig, 2011).

In this global context we developed the SENSIVISE VR-based tool that proposes the simulation of three graduated visual impairments (central Scotoma, Blurred and Tunnel vision) whose levels have been defined with professionals of low vision at the Institut des Hauts Thébaudières. It allows sighted users to navigate and interact within a virtual environment (VE) that includes an apartment with several rooms, and to experiment the difficulties of visually impaired people during activities of daily life. SENSIVISE tool proposes adaptations of the VE in order to facilitate the understanding of the environment and of the tasks.

The objectives of this study are to examine: 1) the impact of visual impairment simulation on perceptions in a VE; 2) the relevance of the adaptations of the VE to improve the perceptions.

2. METHOD

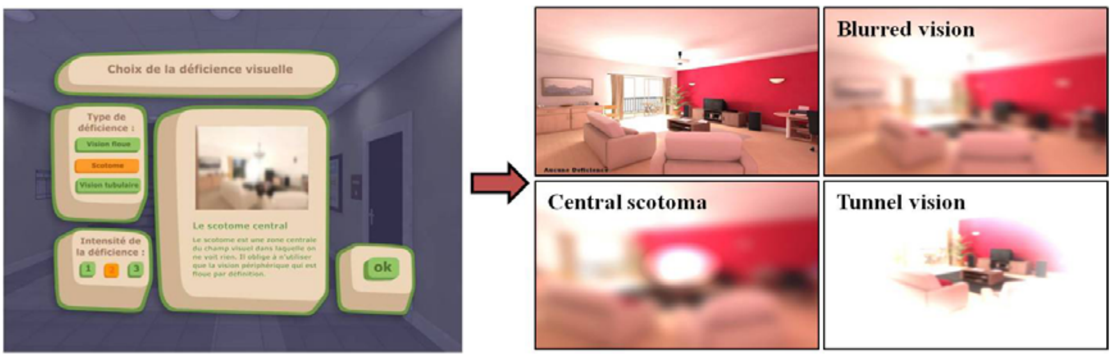
2.1 Participants

This study involved 24 sighted participants (12 M and 12F); all volunteers, recruited by a call for volunteers posted to schools and university library of Laval, France. Their ages ranged between 18 and 74 years (35 ± 13.8).

2.2 Material

SENSIVISE is a VR-based application which was designed to inform and raise awareness about low vision. It simulates the entrance of a building and an apartment with a living room, a bedroom, a bathroom and a kitchen with a laundry room. All the rooms are equipped with 3D objects and furniture, as in a real apartment. Thanks to shaders (i.e. a computer program used to calculate rendering effects on graphics hardware), SENSIVISE proposes the simulation of three visual impairments (scotoma, blurred and tubular vision) which were chosen by the professionals of the Institute of Hauts Thébaudières according to their expertise in low vision. They also defined three levels of difficulty for each impairment: increasing the blurred aspect, decreasing the size of the tunnel, increasing the size of the scotoma (Figure 1). In order to improve perception of places and objects, SENSIVISE also proposes environmental adaptation options such as contrast (e.g. between the walls and the bath), light (e.g. dim light in the bedroom), objects choice (wrong versus right alarm clock in the bedroom) (Figure 2). Finally, SENSIVISE proposes games such as finding items and putting them in a correct order. During this VR-based game, participants are asked to collect pair of objects. The purpose is to show that putting the objects at the right place is very important for visually impaired people, and that looking for objects can become a difficult activity.

When participants interact with SENSIVISE, at first they choose the type and the level of low vision simulation thanks to a menu (Figure 1a). Then they walk in the virtual world using the keyboard and the mouse, and they interact with the objects using the mouse.



a) b)

Figure 1*: A snapshot of the environment. a) allows to choose form and intensity of low vision displayed (on the left); and concurrently inform about the selected form (on the right); b) results of the three simulations; Control condition and Blurred vision on the left and right top respectively; central Scotoma and Tunnel vision down left and right respectively.*

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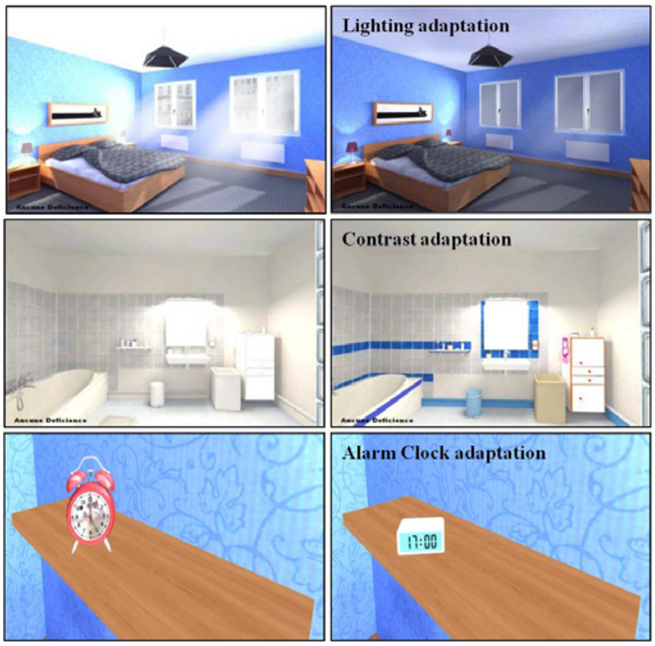

Figure 2: *A snapshot of rooms before and after adaptations; light adjustment in the bedroom; right top; and contrast in the bathroom, middle; alarm clock adaptation, right down.*

2.3 Experimental Design

In order to reach our objectives, four groups were tested corresponding to the control and the three low vision simulated conditions: blurred vision, central scotoma and tunnel vision. Two-rooms, “the bedroom” and “the bathroom”, were chosen for the tests according to a predefined scenario. Participants had to follow three steps: 1) a pre-test, 2) a test and 3) a post-test. In the first step, participants had to answer to a brief questionnaire (Q1) about how they rated themselves as users of computer (keyboard and mouse) according to the following definitions: “beginner”, “expert” and “intermediate”; and if they had prior knowledge about low vision. Then they had to carry out a familiarization procedure with the tool, without any low vision simulation. The testing phase involved the execution of the scenario in each room, in one of the low vision conditions, and was followed by a short questionnaire (Q2). The experiment was completed by a third questionnaire (Q3 post-test) related to self-assessment on the use of the VR-based tool “SENSIVISE” (See Table 1)

Table 1: *The experimental design.*

Pre-test	Test				Post-Test
P: Q1	Scenario 1	P: Q2	Scenario 2	P : Q2	P: Q3
Landing	Room 1		Room 2		
	LV1		LV2		

Q 1, 2, 3: Questionnaire ; P: Participant ; LV 1, 2 : Low vision condition

2.4 Procedure

SENSIVISE's application was displayed on a 22 inches screen which was located at 35 cm from the edge of the desk. The participants sat on a chair in front of the screen, with a mouse and a keyboard on the desk. The evaluator sat behind the participant with a keyboard and a mouse also connected to the application in order to select conditions and adaptations during the test. In addition, the evaluator used a laptop in order to fill out an online questionnaire created for this experiment.

18 participants out of 24 experiment each of the three visually impaired conditions in the bedroom and in the bathroom respectively. Tests were alternated between the participants in order to obtain at the end of the experiment six individuals in each condition: blurred, central scotoma and tunnel vision. The six remaining

participants followed the same scenario but in a control condition without any simulation of visual impairment. The test took one hour and each participant was tested individually and only once.

The experiment started with the familiarization step (pre-test) at the first floor of the VE in order to get familiar with the use of the keyboard to navigate and of the mouse to look up, down and around (i.e. head movements). Then the test step took place in the apartment, at the entrance of each room (bedroom and bathroom) in a visual impaired condition. The participant had to follow the predefined scenario which was enunciated by the evaluator: visual exploration followed by exploration through action while moving inside the room. During the unfolding of the test, participants had to answer to some questions.

In the visual exploration step, participants had 15 seconds to tell in which room they were (Question 1) by exploring the space with head movements. If beyond that time participants did not give a right answer, the evaluator activated adaptations: lighting at first, substituted by contrast if the answer was always bad, and finally both together.

In the exploration through action step, participants had 60 seconds to perform the requested task while moving inside the room. In the bedroom, participants had to find the alarm clock that was on a shelf near the bed (Question 2). Once in front of it, they were asked to read the time (Question 3). If participants were unable to read the time displayed on the alarm clock, two adaptations were tested: lighting and then another type of alarm clock. In the bathroom, participants had to navigate to reach the tablet near the sink and to list all the objects that they perceived on it (Question 2). Adaptations were activated when participants were unable to see all the objects: color contrasts. Then a game was performed, without time-limitation or adaptations, in which the participants had to put in order identical objects by clicking on the objects with the mouse (Question 3).

At the end of each tested room, participants were asked to answer the post-test questionnaire (Q3) about how they perceived the VE, how they interacted, their feeling about low vision and more generally about SENSIVISE.

2.5 Data Analysis

Visual and interacting explorations were performed to assess: 1) the impact of visual impairment simulation on perception; 2) the relevance of the adaptations on perception improvement.

The impact of visual impairment simulation on perception was determined by comparing qualitative and quantitative parameters between low vision conditions and control condition. These parameters include: responses to questions, time of response measured with a chronometer, or behavior assessed by the distance between the participant and the screen. Except for the game, response time was collected only for the good answers (less than or equal to 15 seconds or 60 seconds respectively for the visual exploration and for exploration through action). The time of response was the time elapsed between the end of the formulated question by the assessor and the response made by the participant. The statistical analyses were done using a non-parametric method of Kruskal-Wallis and the significant difference between conditions was analyzed using the Wilcoxon test.

3. RESULTS

Results presented in this section were collected among 24 subjects, 6 in each tested condition (control, blurred vision, tunnel vision, central scotoma). Data from the two sessions for each low vision condition were compared to the control condition. As visual exploration is common to both tested-rooms, data were analyzed in the same part. Data from exploration through action are presented separately for the bedroom and for the bathroom.

According to Questionnaire 1, 75% of the participants consider themselves as expert users of computer (keyboard and mouse) and 50% declared to be familiar with low vision in a general way.

3.1 Impact of Visual Impairment Simulation on Perception

3.1.1 Visual exploration. Individual performance was documented by the number of good answers and the times needed by the participants to answer questions related to the visual exploration session. These data were recorded and analyzed for each study group (Table 2). In the bedroom, all participants of the four groups were able to give the right answer. Participants from the tunnel vision group were the longest to answer. In the bathroom, only three subjects of the blurred vision group gave good answers against 6 in the other groups.

The Kruskal Wallis test comparisons between the control condition with each of the low vision conditions revealed a statistically significant effects ($p_{\text{Value}} = 0.012$). A post-hoc analysis realized by the Wilcoxon test revealed that this statistically significant effect concern only the participants from the tunnel vision group (T) in the bedroom ($W= 3$, $p_{\text{Value}}= 0.009$) and participants from the blurred ($W= 0$, $p_{\text{Value}}= 0.016$) and tunnel vision ($W= 0$, $p_{\text{Value}}= 0.003$) groups in the bathroom (See table 2).

The distance between the participant and the screen was also analyzed (Figure 3, in the bathroom). Compared to the participants from the control condition, participants from blurred vision and central scotoma condition were closer to the screen. The Wilcoxon test revealed a significant difference between participants from the control and blurred vision conditions ($W=33$, $p_{\text{Value}}= 0.013$).

Table 2: *Means, Standard deviations, and test of Wilcoxon values* (*w* and *p) on the recorded data for participants in low vision simulated conditions and controls*

6 individuals in each condition		Control condition (C)	Blurred vision (B)	central Scotoma (S)	Tunnel vision (T)
In the Bedroom	Mean age	29.3±8.3	36.2±11.6	45.2±7.8	32.8±21.1
	Number of good answers	6/6	6/6	6/6	6/6
	Mean Time duration (Seconds)	1±0	1.8±1.2	1.8±1.2	7.3±5.2
	Significant difference				$W= 3$ $p_{\text{Value}}= 0.009$*
In the Bathroom	Mean age	29.3±8.3	42.2±20.5	30.5±13.3	41.5±6.1
	Number of good answers	6/6	3/6	6/6	6/6
	Mean Time duration (seconds)	1.1±0.4	10.6±5.1	1.8±2.0	8.5±5.2
	Significant difference		$W=0$ $p_{\text{Value}}=0.016$*		$W=0$ $p_{\text{Value}}=0.003$*

*$p < 0.05$. significant difference between the control and the low vision group. using the non parametric Wilcoxon test.

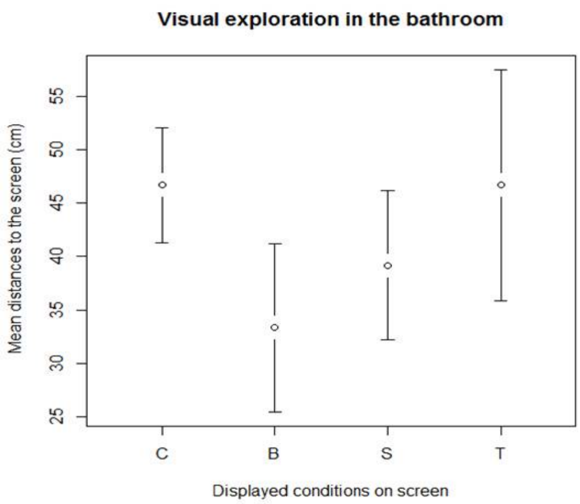

Figure 3: *Mean distances and standard deviations for each group: Control condition (C), Blurred vision (B), Central scotoma (S), Tunnel vision (T)*

3.1.2 Exploration Through Action.

A – In the bedroom. Participants were asked to reach the alarm clock by walking through the VE in one of the selected conditions. All participants from control and blurred vision condition reach the alarm clock, against five participants from the central scotoma and tunnel vision groups (Table 3). The Wilcoxon test revealed significant differences between participants from the control and the blurred groups and between the control and the central scotoma groups. Participants from the blurred vision and central scotoma group were longest to reach the alarm clock compared to the other groups.

In order to perform the next step of the procedure, the two participants who failed to reach the alarm clock belonging to the central scotoma and the tunnel vision groups were placed in front of the alarm clock after 60 seconds. All participants were asked to read the time on the clock. The results showed that, in case of low vision condition, only two participants, belonging to the tunnel vision group, were able to tell the exact time displayed on the alarm clock.

B – In the bathroom. Participants were asked to reach the tablet near the sink to list all the objects they perceived. Participants had to list nine objects, perceived by the control group. Results show that none of the participants from the low vision groups was able to list them in full (Table 4). Comparisons between the control group and each low vision group revealed a statistical significant with Wilcoxon test (W= 36, p_{Value}= 0.002*).

Table 3: *Number of good answers and Mean times (seconds) with the Wilcoxon values.*

In the Bedroom	Control condition (C)	Blurred vision (B)	central Scotoma (S)	Tunnel vision (T)
Number of good answers	6/6	6/6	5/6	5/6
Mean Time duration (seconds)	8.3±3.67	27.3±22.1	50.8±13.1	21.6±21.14
Significant difference		W= 5.5 p_{Value}= 0.046*	W= 0 p_{Value}= 0.0068*	

*p < 0.05. significant difference between the control and the low vision group. using the non-parametric Wilcoxon

Table 4: *Mean number of items found and standard deviation.*

In the Bathroom	Control condition (C)	Blurred vision (B)	central Scotoma (S)	Tunnel vision (T)
Mean Number of items found	9.0±0.0	3.8±1.47	3.3±2.25	4.6±1.21

3.1.3 The game. During this step in the bathroom, participants had to put in order 5 pairs of identical objects by clicking on the objects with the mouse. Data from the game performed by each participant from the low vision conditions were compared to the control condition.

The Wilcoxon test gives significant differences between the control group and each low vision group (see table 5). All participants from the three low vision groups took more time to find and arrange the objects than participants from control group, especially participants from the blurred group and from the tunnel group. The distribution of these times duration is shown on figure 4.

Table 5: *Mean time and standard deviation, recorded from the game in each test condition. Wilcoxon values*

In the Bathroom	Control condition (C)	Blurred vision (B)	central Scotoma (S)	Tunnel vision (T)
Mean time duration (seconds)	62.33±32.18	239.66±146.34	195±87.28	343±90.48
Significant difference		W= 1.0 p_{Value}= 0.004*	W= 0.5 p_{Value}= 0.006*	W= 0.0 p_{Value}= 0.002*

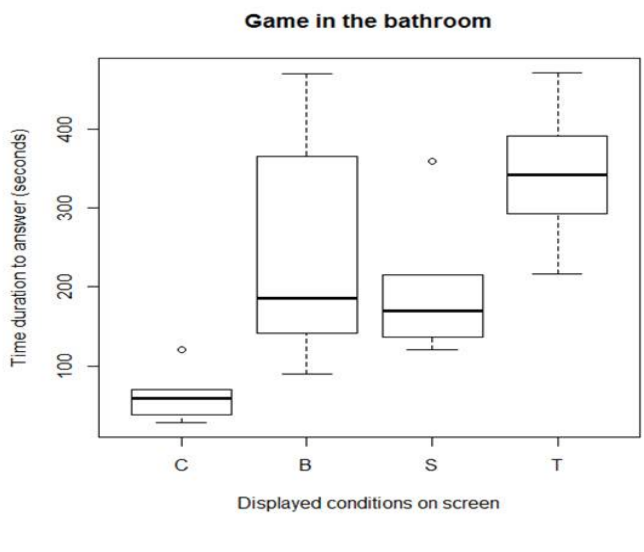

Figure 4: *The game performance: Distribution of time duration to answer in each group: Control condition (C), Blurred vision (B), Central scotoma (S), Tunnel vision (T)*

3.2 *Relevance of Adaptations*

In order to attempt to improve perception, adaptations of the VE were proposed to the participants who failed to give good answers. The adaptations were introduced one by one and then combined. During visual exploration, reducing lighting was sufficient to help the three participants from the blurred group who failed to give good answers when they had to recognize the bathroom.

During exploration through action,

- In the bedroom, with a dim light or a digital clock none participant was able to read the time in blurred vision or central scotoma. Contrariwise, 3 out of the 4 participants who were not able to read the time, succeeded after changing the clock. And then, the combination of the two adaptations helped the only person who failed in the group to read time.
- In the bathroom, adding contrast helped two participants from the blurred vision group and one participant from each central scotoma and tunnel vision groups to find all items. In addition, light and contrast together allowed two participants from the tunnel vision group to list all the items.

3.3 *Perception and Navigation in SENSIVISE*

During the post-test, each participant had to evaluate in a graduate scale how he perceived the VE for each low vision condition. Except for the control condition group, all participants reported a very bad perception and this in the two rooms tested. And finally, in another graduate scale how they rated the navigation in SENSIVISE application; results are proposed in Figure 5.

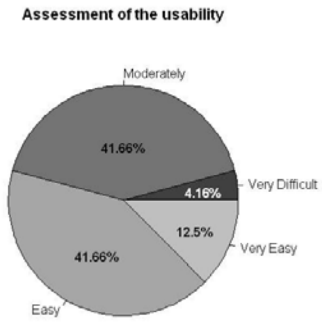

Figure 5: *Usability assessment of the SENSIVISE application for all participants*

4. DISCUSSION

According to the study results, perceiving a VE in low vision condition is not easy. Although almost all participants answered well the questions about visual exploration, times were longer for participants in the low vision conditions compared to control condition. It seems that in the case of a global view, when vision is blurred or when the peripheral visual field is limited, as in a tunnel vision, the observation times are longer and participants tend to be closer to the screen in particular with blurred vision. Moreover, when the task requires vision for detail, times are longer with central scotoma vision compared to the other groups. Studies in this direction have shown that persons with central field loss have reduced acuity and contrast sensitivity, and read quite slowly (Legge et al., 1992).

The questionnaires chosen for this test were related to the SENSIVISE environment but also to the real needs of people with low vision in terms of lighting and contrast. Indeed, contrast sensitivity is crucial to many human visual activities including reading, object recognition and mobility. Studies have shown that reductions in contrast sensitivity (rather than visual acuity) are related to instability and falls in the elderly (Turano et al, 1994; Lord et al, 1991, 2000; Buckley et al, 2005). In addition, contrast adaptation studies using both behavioral and neurophysiological methods support the view that the adaptation produces a functional benefit by enhancing contrast sensitivity around the adapting contrast (Gardner et al., 2005).

The adjustments of light and contrast proposed in our study helped some participants from low vision conditions to give good answers. Moreover, the digital clock as presented here in SENSIVISE only helped people with tunnel vision. Many models of alarm clock exist in SENSIVISE, but to compare our results with another experiment that is underway, this alarm clock was chosen.

At the end of the test, all participants stated that they had a great difficulty to distinguish shapes and objects and thus to reach the requested objectives, and felt lucky to see much better without low vision simulation. For the usability aspect of SENSIVISE, 4.16% of those tested reported having trouble using the keyboard and mouse to navigate in the VE.

As a result, the impact of the visual impairment of perceptions in a VE was achieved. However, the relevance of adaptations was not huge in this test and is currently tested in the context of visual impairment with visually impaired persons.

Information collected through SENSIVISE about how low vision can affect our cognitive abilities and our reaction times may help the sighted people to adopt a best attitude towards the visually impaired persons. Our future aim is to provide the SENSIVISE application for educational institutions and free internet access to inform about low vision and therefore increase the well being of all.

5. CONCLUSION

SENSIVISE is a VR-based application that was created to raise awareness about low vision, by providing information on some forms of visual impairment and on their impact on everyday tasks. Through this study, all participants understood the effort of perception and the difficulties of action met when their vision was impaired. This study allowed us also to know the limits of the proposed adaptations of the VE for certain forms of visual impairment simulation. In future work, we will try to find out if the behavior of visually impaired persons interacting with SENSIVISE (in normal vision condition) is similar to that of sighted people interacting in impaired vision condition.

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Dynamic spatial positioning system based on sounds and augmented reality for visually impaired people

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ABSTRACT

This paper presents an application which intends to exercise spatial association of a three dimensional stimulus with its corresponding motor feedback, inspired on the Ping Pong Game. The application uses a low cost and easily built artifact, enhanced with an augmented reality layer provided by a free authoring tool. The augmented reality resources empower the artifact with sound feedback, so visually impaired people can use it. Besides, the visual feedback can be useful for non-visually impaired people and also for therapists, who can prepare exercises, promoting a therapeutic application and involving social inclusion capabilities.

1. INTRODUCTION

Developers of serious games address purposes others than pure entertainment, such as education, defense, scientific exploration, health care, etc. (Abt, 1987). The lack of physical activity is a critical health concern for individuals that are Visually Impaired (VI), because they usually have few opportunities and incentives to engage in physical activities. In this sense, it is important to provide situations to support an adequate fitness and a healthy standard of living for them (Azuma, 1987).

Technology helps create health serious games, once the success and proliferation of video games are growing making them more relevant and more responsible (Beato et al, 2009).

One technology, which can be easily used into serious games presenting low cost, is the Augmented Reality (AR). Early AR definitions say that AR was obtained only through visual elements (Cerqueira and Kirner, 2012; Farlex, 2012); however, the use of audio and haptic interactions, associated in time and space, extends the AR definition.

In addition, the development of interactions using audio and haptic resources expands the AR concept to a wider definition, which involves the real world empowered with virtual objects (visual, audio, and haptic) with their related drivers (projectors, speakers, and haptic devices).

Artifacts, including the interactive ones, can be implemented using AR, once it provides a low cost and can be easily distributed to interested users. Several interactive artifacts for rehabilitation are being developed, most of them applied in motor rehabilitation. There are few examples focusing on cognitive rehabilitation (Grasielle et al, 2007; Gunasekara and Bendall, 2005; Kato and Billinghurst, 1999).

Interactive artifacts based on AR technology may fulfill the following requirements: (Kirner and Kirner, 2011):

- The artifacts for cognitive application have to involve multi-sensory knowledge, perception, memory, attention, logic and motor control, in order to allow the preparation of cognitive exercises.
- The physical parts of the artifact has to be built with ordinary materials, involving a simple process, presenting availability and low cost. For this, it could be adopted materials such as Styrofoam, cardboard or wood, to implement the physical structure, always followed by instructions and templates.

- The logical parts of the artifact have to use AR. Authoring tools for rapid prototyping can make easy the development of applications.
- The user interactive actions on the artifact must be tangible. This property, due to the coincident physical and virtual points, allows the interactions, since when the user touches the interacting device (pointer) in the artifact, he “feels” the contact and the virtual action point is enabled. This characteristic is important, because it gives more comfort to the user. When the points are placed into the 3D space, without physical association, they demand more ability and concentration from the user, to collide the pointer with the virtual points.

A simple way to mix virtual information in the physical user environment is using a webcam, which captures a live video stream of the real world, and track some features, allowing the computer to add virtual information to the real world. Figure 1 shows examples of AR setup with a camera (Kirner et al, 2012a). The system in Figure 1a uses a top, non-mirror view, where the camera is placed with a tripod, the video seem on the monitor is the same view of the user, and the artifact can be seem on the real and mixed worlds. Figure 1b uses a mirror view, usually achieved by a notebook camera, and the artifact is usually hold by the user body to be seem by the camera, which does not easily allows the user to see the real and augmented artifact.


(a) (b)

Figure 1. *Augmented reality examples. (a) Non-mirror view and (b) Mirror view.*

Serious games focus on three inter-related aspects: rehabilitation, socialization and inclusion.

Rehabilitation is defined (Kirner et al, 2012b) as a dynamic process of change in lifestyle, due to a disease or traumatic incident. The success of a rehabilitation program depends on several factors, such as timing, type of program, medical management, and discharge planning. This can be achieved by multidisciplinary ways, including medical, nursery or socialization (Lee, 2012). Socialization is an essential element, which is defined as the acquaintances of necessary skills for people perform as a functioning member of their society, giving them the conditions to be socially included (O’Neil, 2011).

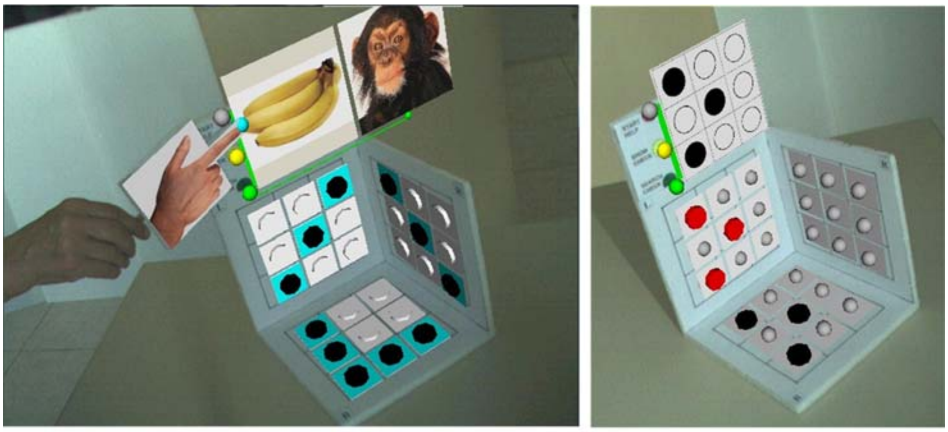
This article presents a computer-based application, inspired on the Ping Pong game, using a low cost and easily built artifact, which aims at providing cognitive and motor development exercises, as well as socialization. The application uses AR technology, which is responsible to give sound feedback to visually impaired users and visual feedback to therapists and non-visually impaired users.

The following sections present the Related Works, showing some cases using video game controller; the Artifact, which shows the development of a grid artifact that helps in the game; Interaction, which shows how the augmented reality layer performs to create the application; User, showing how the research can be used by user and therapists; and the Conclusions and future works.

2. RELATED WORK

Some related studies include rehabilitation efforts, based on pure augmented reality and on video-game controllers, as the Nintendo Wiimote Controller (Morelli et al, 2010).

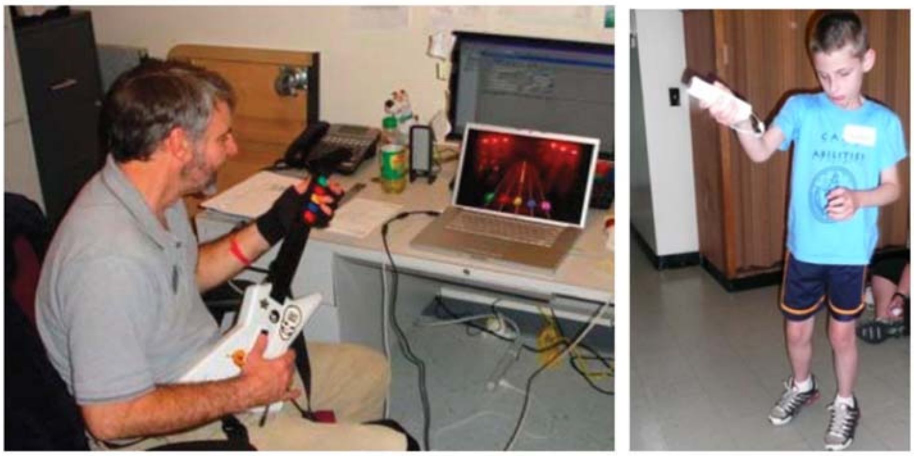
Kirner and Kirner (2010) developed a cognitive serious game focused on rehabilitation, related to memory and association activities. In this serious-game, an artifact (Figure 2a and 2b) was developed in order to empower an AR layer.



(a) (b)

Figure 2. *(a) and (b) examples of artifacts empowered with AR.*

Another application is the blindHero (Rego et al, 2010; Yuan and Folmer, 2008). In it, the user, wearing a haptic glove, receives the input stimulus to press the guitar button (Figure 3a). In the VI-Tennis application (Morelli et al, 2010), the user receives tactile feedback (from the Wiimote Controller) and audio cues to play the game (Figure 3b).



(a) (b)

Figure 3. *(a) blindHero application; (b) VI-Tennis application.*

3. ARTIFACTS

In general, games interfaces applied to visually impaired people are developed to give tactile and audio feedback, using different textures and sounds. To move into the game space, the user must have a three-dimensional (3D) sound perception. One way to implement the spatial perception based on sound is varying frequency and acoustic intensity in the space using the three coordinate axes:

- Horizontal axis. The audio is placed using stereo balance.
- Vertical axis. The audio is placed by the frequency, in which a higher pitch indicates a higher height and a lower pitch indicates a lower height.
- Deep axis. The audio is placed in association with the volume, in which higher volumes indicates that the object is closed to the user.

Figure 4a shows the 3D audio placement, which helps the VI user to interact with the game. Figure 4b shows how to control the object speed (in this case, a ball). Four stages, defined by four time intervals, control the ball speed, so, with long time intervals the speed is decreased and with short time intervals the speed is increased.

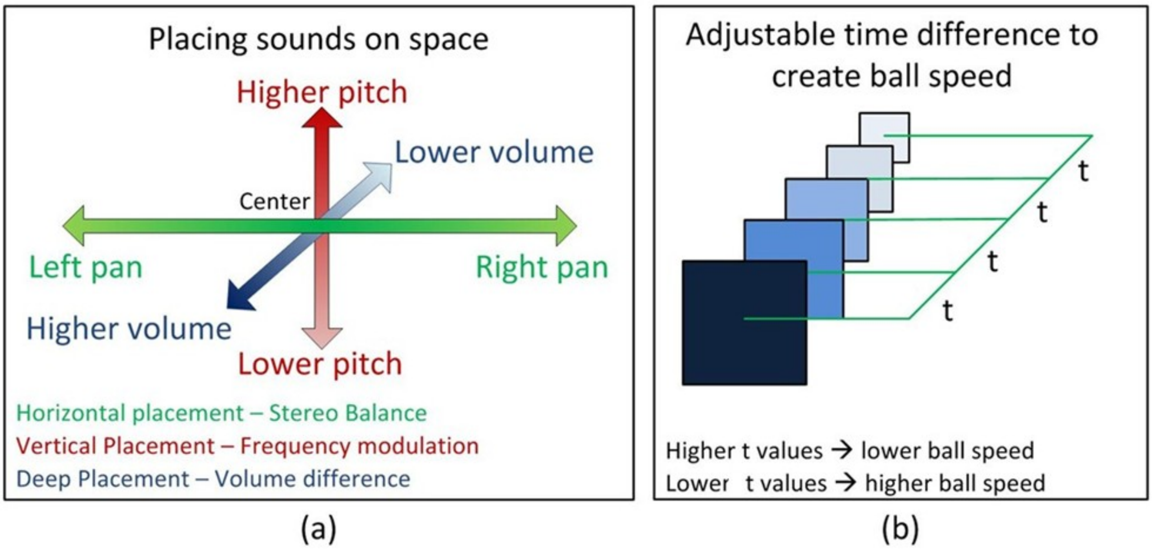


Figure 4. *(a) Sound placement into a 3D space; (b) Adjusting the time intervals to control ball speed.*

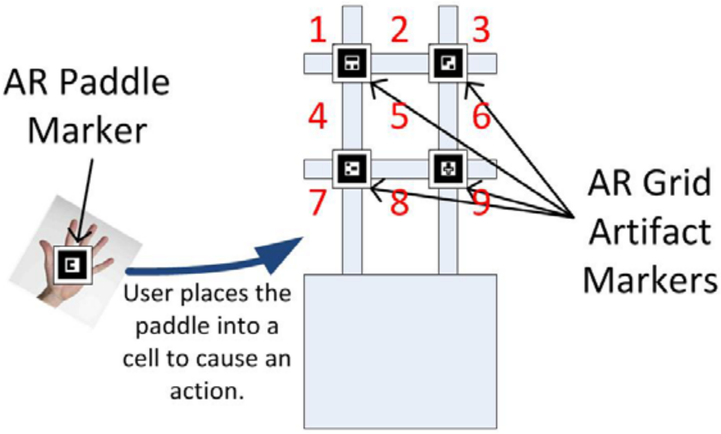


Figure 5. *Grid Structure with nine cells and four AR markers on the Artifact.*

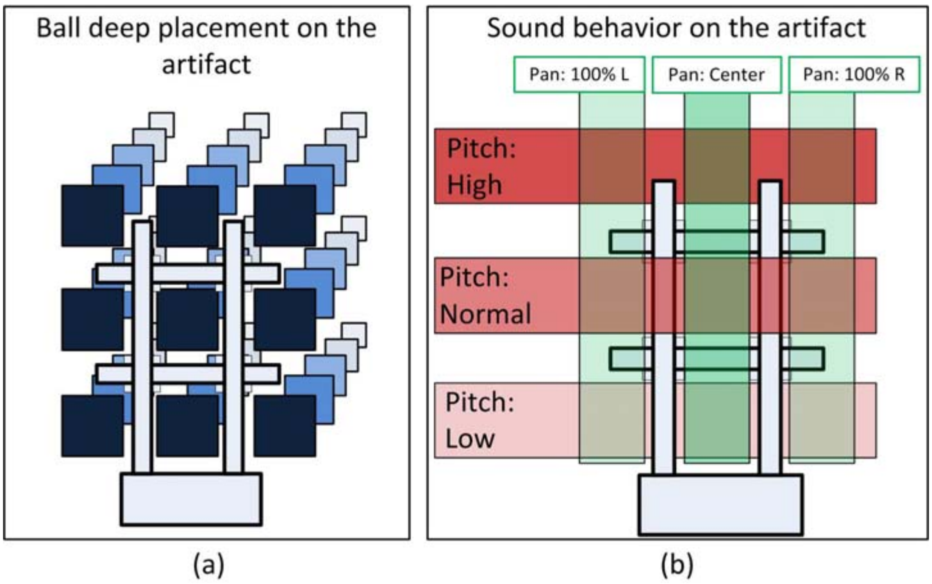


Figure 6. *(a) Deep placement; (b) Sound behavior.*

To achieve an interface that helps the VI user to play the game, a Grid Structure (Figure 5) with AR markers was developed. Thus, the VI user can place the paddle into the correct playing space, in order to correctly hit the virtual ball.

The inclusion of the virtual layer enables the AR properties. In this sense, each artifact cell has a deep placement (Figure 6a), to create the sensation of ball movement. The vertical and horizontal placement are interlaced, to provide nine possible combinations of pan and pitch (Figure 6b), so that the user can find the correct cell by its sound; for example, a ball coming in left pan and with low pitch indicates to the user that this ball is in the bottom left cell.

A second artifact was built to provide real time changes made by therapist. It has three more cells on the top of the grid (Figure 7a) and it is used to select the ball speed. Figure 7b shows the rear (camera) view of the artifact, where the augmented reality markers is captured by the camera. Figure 7c shows both artifacts: the user artifact, on the left, and the therapist artifact, on the right. Figure 7d shows the prototype being used by a therapist with paddles. The upper paddle controls the ball speed and the lower paddle controls the position where the visually impaired person has to place his/her paddle on his/her artifact to hit the ball using sounds driven his/her movements.

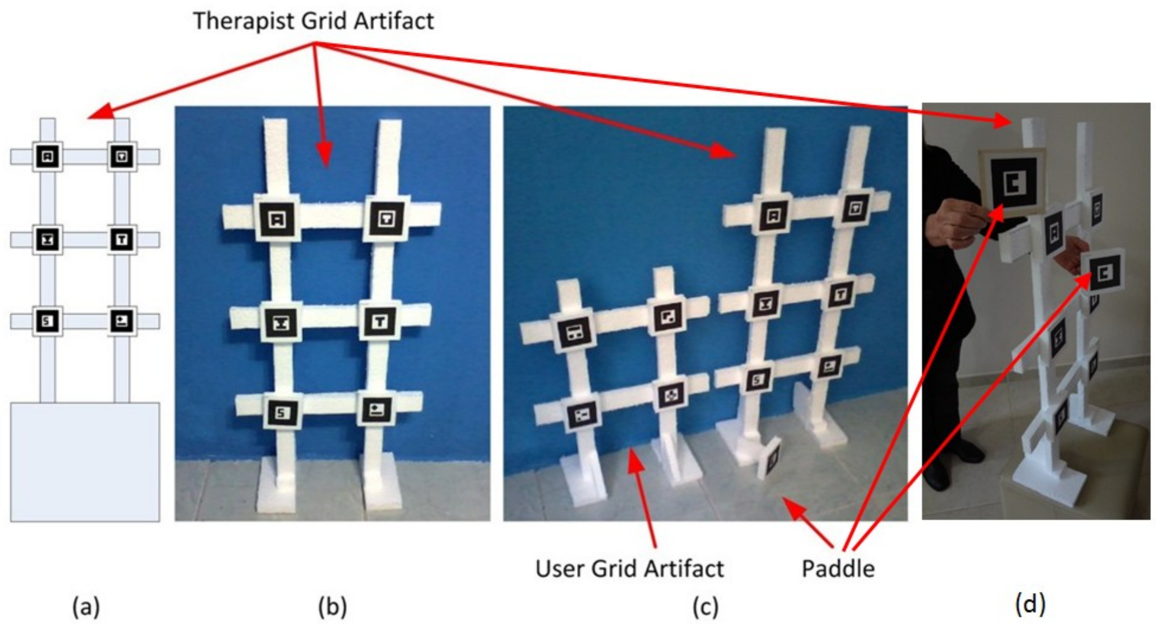


Figure 7. *Artifact Views: (a) Conception; (b) Therapist; (c) User and Therapist; (d) Prototype in action.*

The prototype artifacts were developed using Styrofoam, which is an easy to use material. A final artifact could use wood or plastic material. In this work, we used the cheapest material.

In order to create the AR layer, it was decided to use the marker approach (Cerqueira and Kirner, 2012), offered by the basAR application, which will be explained in the Interaction Section. The user artifact includes four markers and the therapist artifact has six markers. Each paddle presents only one marker. All markers must be different from each other, to be correctly recognized.

4. INTERACTION

The development of the AR application followed some hardware and software requirements:

- Hardware: computer with a webcam, capable to run the software.
- Software: program used to create the augmented world.

In these experiments, a notebook with an incorporated webcam was used to acquire the real world and the markers' information. The software chosen was the basAR (Behavioral Authoring System for Augmented Reality) developed by Cerqueira and Kirner (2012), which allows a programming procedure based on action points. Action points are reactive zones placed apart from the marker reference that, when stimulated by a control markers (the paddle), may give visual and auditory feedback.

Figure 8 exemplifies how the action points work. A base marker holds the points and, when the control marker action point collides with the base points, it causes programmed feedback.

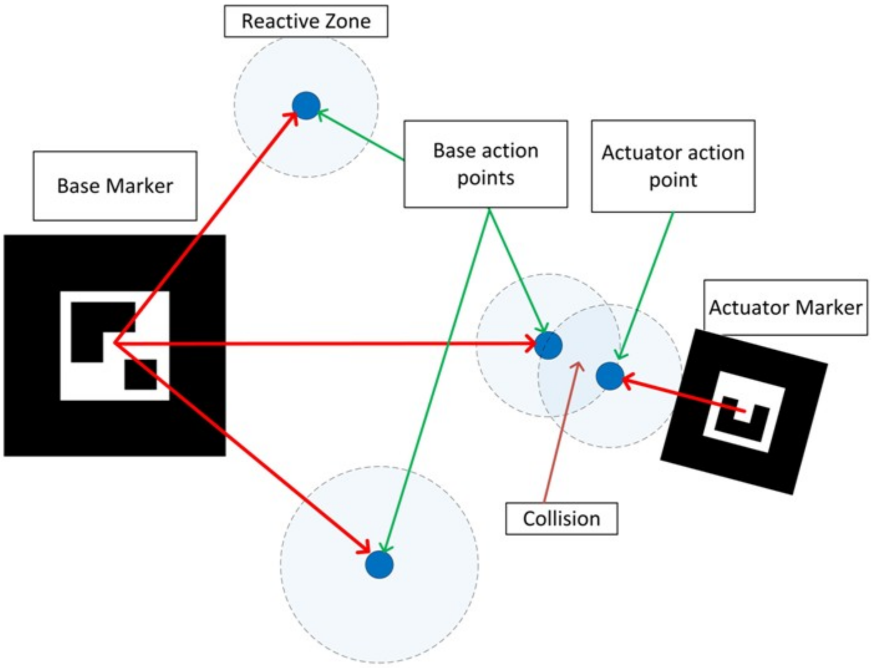


Figure 8. *How basAR action point works.*

Each artifact has a number of action points related to the amount of grid cells, (the user has nine points, and the therapist has twelve points).

The basAR Authoring Language (basAR-AL) uses a state machine concept driven by events, which can be divided into user interaction, programmed changes and math results.

- The user interaction makes changes on the state machine, by action point collisions.
- The programmed changes make changes on the state machine, going to a new state, when the old one is activated.
- Math results make changes on the state machine, by testing some variables. Depending on the result, the state machine can move to other state.

Additional information about the basAR-AL tool is available on the basAR documentation (Cerqueira and Kirner, 2012).

Possible use scenarios for the AR application here discussed are presented in the next section.

5. USING THE APPLICATION

The application discussed in this paper presents four possible using modes, which could be chosen, depending on the intended activity (user x computer, user x user, user x programmed sequence, or user following therapist), categorized in: Game and Therapeutic Modes.

- Game Mode. This mode allows the VI user to dispute matches at home or anywhere, using the system. The matches can be held in two cases: against the computer or against other player. It is important to note that, as the system also provides a visual feedback and both feedbacks (sound and visual) are blended, it also allows non-VI users to participate of the game, turning it an inclusive application and contributing to the socialization of VI users. Schemes of these two cases are illustrated in Figure 9.
- Therapeutic Mode. This mode allows a therapist to introduce a series of exercises to VI users in the activities. This can be achieved by two cases: against a pre-programmed sequence to achieve a desired result, or driven by the therapist, where the position of the sound is chosen by the therapist and one of three speeds can be selected on the fly. Schemes of these two cases are illustrated in Figure 10.

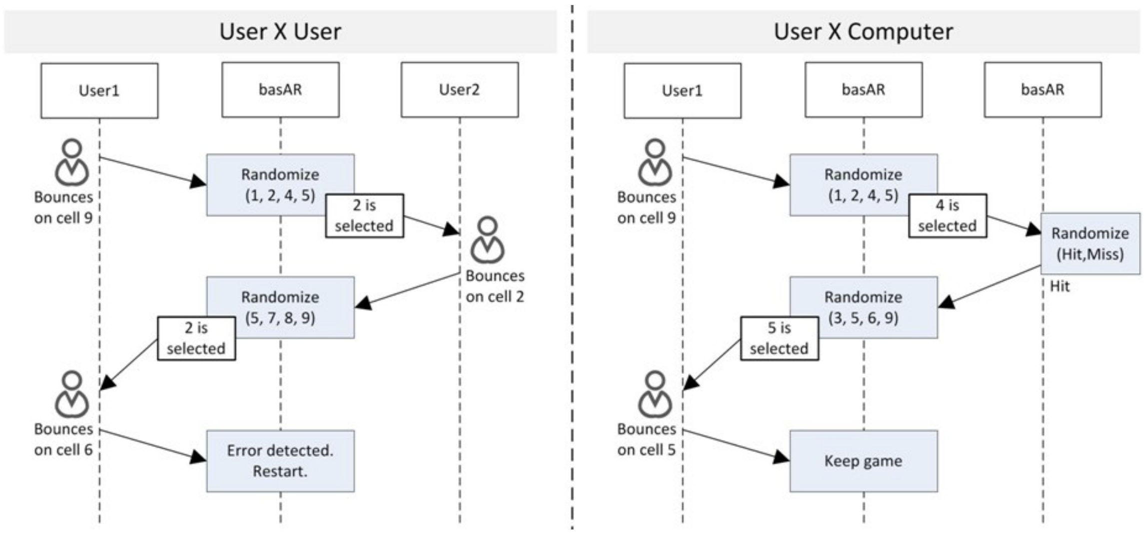


Figure 9. *Game Mode schemes.*

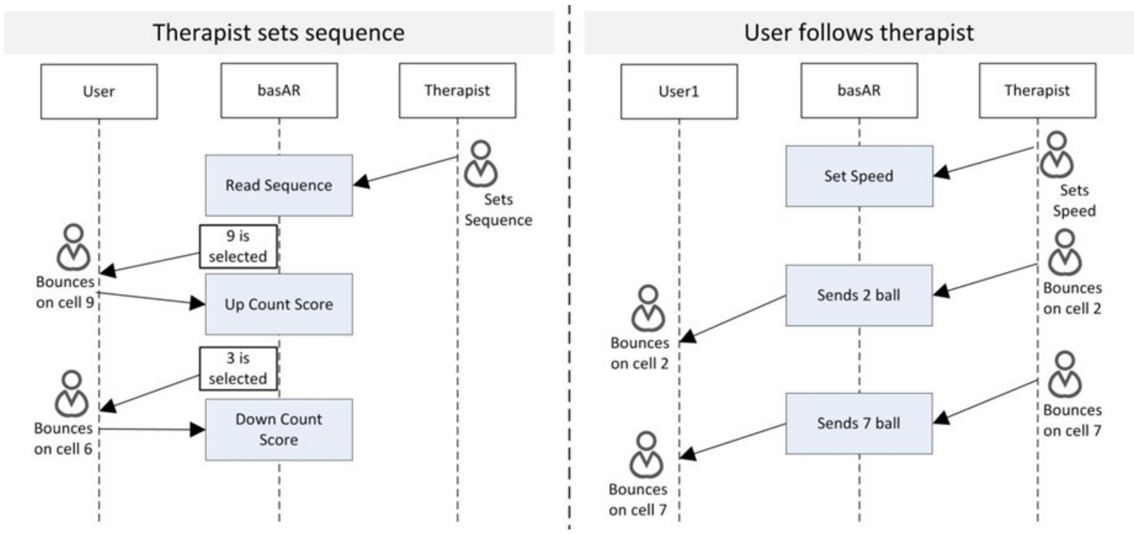


Figure 10. *Therapeutic Mode schemes.*

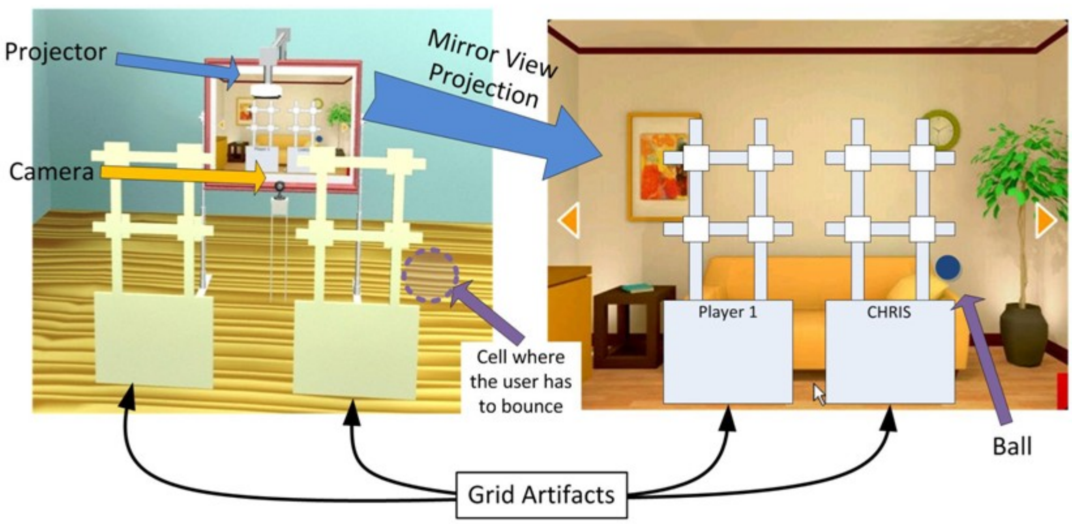


Figure 11. *Game Mode Sketch: User X User.*

Figure 11 presents a sketch of a Game. In it, two artifacts are positioned in front of a camera, which acquires the video and sends it to the projector. The projection shows a mirror view of the users and the augmented layer, showing the virtual blue ball and issuing a sound.

6. CONCLUSION

This paper presented and discussed a low cost, interactive and inclusive application, inspired on the Ping Pong game, which uses a Styrofoam grid artifact to help users to play. The game uses an Augmented Reality environment, implemented with basis on the software basAR, to empower the artifact with virtual properties. The article describes development aspects and some utilization scenarios.

Comparing the presented application with commercially available gaming technologies, it is possible to identify that this system is more affordable, since many users already have computers with cameras. In this sense, it is necessary to build the artifact, which is not a difficult task.

The positive points, observed by some users, were:

- The easiness of acquire the calibration, which is desired in the game-mode, when the user can practice at home.
- Therapists pointed out the inclusive characteristic as an important issue, as some visually impaired children could play with their brothers and friends, making important steps to integrate both worlds.

The identified negative aspects include the fact that a visually impaired user needs help to build the artifact. Besides, the therapists pointed out the difficulty to create the pre-programmed sequences, which could be supported by a future friendly interface.

The application and further information about the implemented augmented reality spatial game are available on Kirner et al (2012b).

In a future version of the application, the negatives aspects will be considered to improve the therapeutic use, such as the inclusion of a burst mode. This will make possible the therapist create a sequence of steps to send to the player. It is being analyzed a development option by means of an ARDUINO hardware.

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Videogaming for wayfinding skills in children who are blind

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ABSTRACT

There are several problems faced by people who are blind when navigating through unfamiliar spaces, and especially open spaces. One way to mitigate these problems is by getting to know the spaces prior to actual navigation, through the use of virtual environments represented through audio and haptic interfaces. In exploring the possibilities for further improving navigation through such spaces; it was especially interesting to study the option of simulating the real body movement of a learner who is n during his interaction with a virtual environment. To achieve this the design, implementation and impact evaluation of an audio and haptic-based videogame called MovaWii is proposed, in which a real physical space is represented virtually, where learners who are blind interact through their own body movements and use of the Wiimote controllers of the Nintendo Wii console in order to navigate through unknown virtual spaces. The results demonstrated a videogame that allows for the development of orientation and mobility skills in learners who are blind, as it serves as a supporting tool for the construction of a mental map of the virtual space navigated through the integration of its audio and haptic components. In addition, learners could transfer the information obtained from virtual to the real world physical space, through which they were then able to navigate autonomously and efficiently.

1. INTRODUCTION

Through virtual environments, people who are blind can become familiar with real-life, unfamiliar, closed spaces before actually physically navigating them. The user's interaction with these virtual environments can occur through spatialized sound and audio-based interfaces (Sánchez and Elías, 2007; Sánchez *et al.*, 2009, 2010a), and/or through haptic-based interfaces (Sánchez and Espinoza, 2011; Sánchez and Mascaró, 2011; Sánchez *et al.*, 2010). During this interaction, the user receives information from the virtual environment that facilitates his navigation through these spaces in the real world, as the experiences enhance the user's orientation and mobility (O&M) skills (Lahav and Mioduser, 2008, 2008a; Sánchez and Espinoza, 2011). In addition to this, serious videogames contribute significantly to the development of various cognitive abilities in both sighted and visually impaired learners (Sánchez and Elias, 2007; Sánchez and Espinoza, 2011; Sánchez *et al.*, 2010, 2010a; Yuan, 2009; Yuan and Folmer, 2008).

Based on this, it is relevant to research how the development of O&M skills is fomented in learners who are blind, through a tool that integrates the characteristics of serious videogames and virtual environments. This paper presents the design, implementation and cognitive impact evaluation of an audio and haptic-based videogame called MovaWii, in which a real-life, physical space is virtually represented, and with which learners who are blind interact through their own body movement and use of Wiimote controllers of the Nintendo Wii console in order to navigate through unfamiliar virtual spaces. The objective of this videogame is to develop O&M skills in learners who are blind; supporting the construction of a mental map of the virtual space navigated through the integration of its audio and haptic components, in order to then transfers this information to the real world physical space, where learners are able to perform autonomous and efficient navigation.

2. RELATED WORK

If real-life surroundings are represented through virtual environments, it is possible to create several training applications that allow a user who is blind to interact with the elements in the simulated environment during navigation (Sánchez *et al.*, 2009, 2010a). Videogames, when integrated with virtual training environments, represent an important tool for the development of various abilities, and O&M skills in particular (Squire, 2003; Steinkuehler, 2004). For example, AbES (Sánchez *et al.*, 2009, 2010a) allows the creation of videogames that integrate virtual environments, focused on the mental construction of real and fictitious environments by users who are blind navigating through virtual environments, using the keyboard of a computer in order to execute actions and receive audio feedback to support O&M.

Haptic interfaces have come to represent a significant contribution to the cognitive development of learners who are blind. There is previous evidence from work with interfaces that provide force-feedback by using different technologies, and provide the user with differing haptic sensations, generating a higher degree of realism in the user's interaction with virtual environments (Sánchez, 2008). Through the use of Novint Falcon and Sensable Phantom haptic devices, a learner who is blind can recognize surfaces, objects and graphics by just using his hands (Lutz, 2006; Sánchez and Espinoza, 2011; Sánchez and Mascaró, 2011; Yu and Brewster, 2002). In this way, the user receives haptic feedback, which allows him to recognize objects, walls and hallways in the virtual environment (Lahav and Mioduser, 2004, 2008, 2008a; Sánchez and Espinoza, 2011; Sánchez and Mascaró, 2011).

It is also possible to allow for a user, either blind or sighted, to interact with a software program or videogame by using the movement of his own body as input, increasing the degree of interactivity and encouraging mobility (Lange *et al*., 2010). MOVA3D is a videogame in which a real-life, closed space is represented virtually, through which the user navigates by turning around his own axis, over a specially adapted carpet that detects movement (Sánchez *et al*., 2010).

A simple and low-cost way to detect the user's movement is to utilize the Wiimote controller of the Nintendo Wii console, and specifically there is evidence of a "finger-tracking" system by using the Wiimote (Williams, 2010). Research has also been done regarding the use of virtual environments that people who are blind can explore by using Nintendo Wii devices, with audio and haptic feedback, facilitating and supporting the construction of cognitive maps and spatial strategies (Evett *et al.*, 2009).

As such, it is relevant to research the development and use of serious videogames based on audio and haptic interfaces that integrate virtual training environments in which users who are blind interact through their own body movement, allowing for the development of O&M skills.

3. MOVAWII VIDEOGAME

MovaWii was proposed based on these interface elements, consisting of the virtual representation of a real-life plaza through audio and haptic interfaces, in which a learner who is blind has the objective of finding a lost jewel by using the Wiimote controllers.

In navigating through a virtual plaza searching for the jewel, the learner must be able to avoid various obstacles in addition to sectors that are off limits. To find the jewel, the player can consult a compass, which indicates in which direction the jewel is located. To change direction, the learner must stand and turn over his own axis to the degree considered necessary, and the game automatically detects the player's change in direction.

MovaWii was developed using C# language and .NET Framework 4.0, through Microsoft Visual Studio 2010 Ultimate development environment. To integrate the characteristics of the Wiimote controller into the videogame, the WiimoteLib v1.7 library was utilized.

3.1 Design

The videogame virtually represents a real, physical place, through which learners who are blind must navigate in order to find a lost jewel. This real-life, physical place consists of a plaza that is made up of navigable sectors, sectors that are off limits, and obstacles such as trees, playground equipment, light posts and benches. In order to model the virtual environment, two public plazas were used: the Ovalle Plaza in Santiago, Chile, and the Izidor Handler Plaza in Viña del Mar, Chile. These plazas were diagrammed and scaled with their respective components, in order to incorporate them into the videogame. It is important to point out that as part of the videogame's design the grass was considered as an obstacle (or restricted area), in order to limit the learners´ movements. This allows learners who are blind to navigate only over the graveled and paved paths, as in each of the respective plazas such paths are clearly demarcated.

To navigate through the physical surroundings, a user who is has to use the clock orientation system (Sánchez and Elías, 2007), turning around his own axis according to the indications provided by the software. In order to detect the user's turns, a wireless bar with infrared LEDs was utilized together with a Wiimote controller (see Fig. 1). The Wiimote controller hangs from the ceiling in the room where the software is utilized, so that the infrared detection area is facing downwards. The user must stand directly below the controller, wearing a jacket that has the wireless infrared bar attached to the back. In this way when the user turns, the infrared LEDs turn with him, and the Wiimote controller detects the variation in the position of the infrared LEDs. In order to aid the user in determining the correct position in which it is necessary to stand, a plastic circle was placed on the floor that serves as a guide to demarcate the space where the players must stand in order to be appropriately detected by the Wiimote controller.

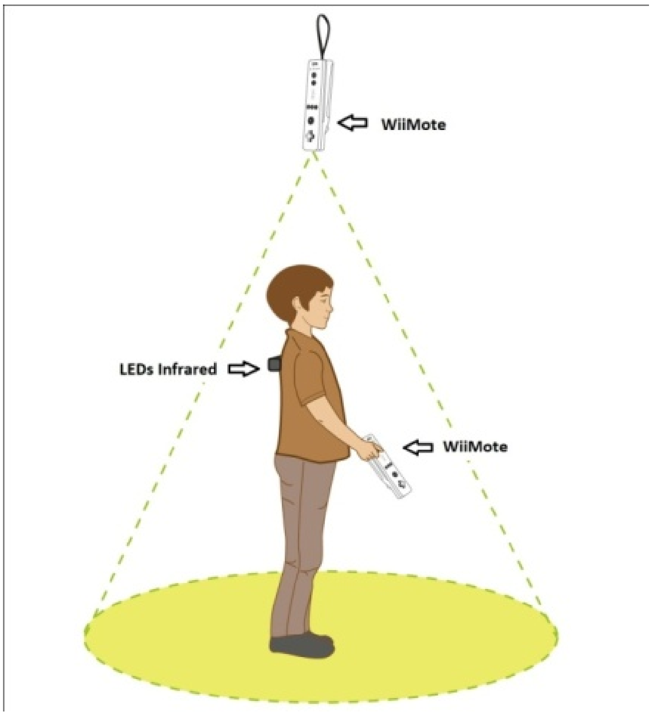

Figure 1. *Hardware montage to interact with the videogame.*

In addition the use of a second Wiimote controller was incorporated, which the player holds in his o hand and uses like a cane for users who are blind (see Fig. 1). Through the use of two specific buttons (the A and B buttons), the user can consult the compass (obtaining a clue regarding the clock direction to which he must turn in order to find the jewel) and move forward a step in the user's current direction (direction that is detected by the other Wiimote based on the position of the LEDs). It is important to point out that these actions can only be performed if the learner is holding the Wiimote controller at an angle that is similar to the common use of a cane (at least 45°, between the axis of the body and that of the arm).

3.2 Interfaces

3.2.1 Audio Interface. Consists of a set of iconic sounds associated with the objects and actions performed by the user. Every time the user moves forward, a sound representing a step is heard; similarly, when the player bumps into objects or obstacles, a sound representative of a collision is heard. In order to provide the player with an audio clue regarding the location of the jewel, an alarm sound is used that increases in volume as the players gets closer to the jewel, and decreases in volume as the players moves farther away from it. In addition, there is a component of recorded speech using AT&T's free web Text-to-Speech engine. These recorded speech phrases are used to indicate to the player the direction in which the jewel is located when he consults the compass. Also, speech was recorded that is used to provide feedback regarding the relative direction in which the player has advanced compared to the previous direction in which the player had moved.

3.2.2 Haptic Interface. This consists of vibration feedback provided by the Wiimote controller that the player holds in his hand, and which acts as a cane for user who is blind. Every time the player bumps into an object, he feels an intermittent vibration in his hand. In addition, when the player moves his hand and no longer holds the controller in the position of the "cane" (at least 45° between the axis of the body and that of the

arm), he feels a continuous vibration in his hand in order to alert him that the cane is not in an appropriate position for use.

3.2.3 Graphic Interface. This interface was designed so that a facilitator (an aide who provides on site support during the interaction with the videogame) can observe the player's location when navigating through the virtual environment. Consists of a bird's eye view of the virtual space (see Fig. 2), in which it is possible to distinguish the navigable areas (beige colored areas in Fig. 2) and non-navigable areas (all that is not beige in Fig. 2) in the plaza represented by the game, in addition to the user's position and direction at any given moment (red dot in Fig. 2), as well as the location of the jewel (yellow dot in Fig. 2).

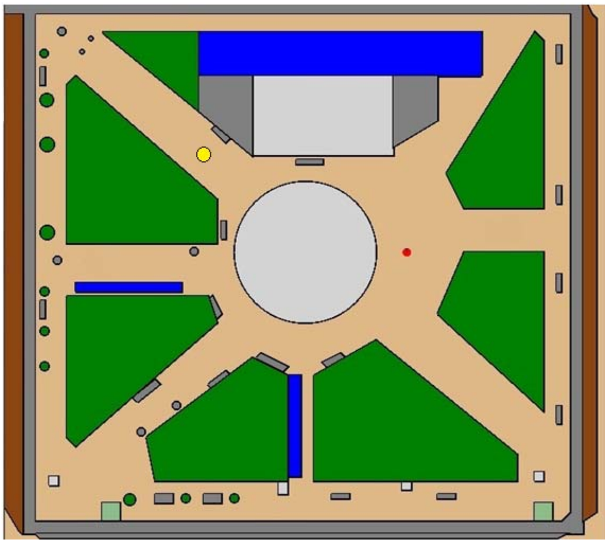

Figure 2. *Graphic interface of the videogame.*

4. METHODOLOGY

4.1 Sample

The sample was made up of 20 learners (7 female; 13 male), in which 11 of them are between 6 and 8 years old, from the first years of primary school at the Santa Lucia Educational Center in the city of Santiago de Chile. The 9 remaining users are between 9 and 15 years old, from primary school at the Antonio Vicente Mosquete Institute in the city of Viña del Mar, Chile. Among the total sample, 4 learners are totally blind and 16 possess residual vision. All of them are legally blind.

4.2 Instruments

4.2.1 Evaluation Guidelines for O&M Skills. This is an evaluation instrument that serves for gathering data and the collection of information regarding O&M skills. This *Evaluation Guidelines* was utilized as both a pretest and posttest during the study, and is made up of 5 dimensions: *Sensory-Perceptual Development*, *Psychomotor Development*, *Development of Techniques without Mobility Aides*, *Development of Initial Cane Techniques, and Development of Concepts*. In order to evaluate these dimensions, 40 items were evaluated on a scale from 0 to 2, in which 0 implies that the item was not achieved (NA), or that the learner was unable to perform the requested behavior; a value of 1 corresponds to an item in process (IP), or that the behavior requested of the learner was inconsistent; and a value of 2 corresponds to an achieved item (A), which implies that the learner performed the requested behavior successfully.

The dimensions measured by the *Evaluation Guidelines for O&M Skills* are:

- *Sensory-Perceptual Development, made up of the sub-dimensions Audio Sensory-Perceptual Development and Tactile Kinesthetic Sensory-Perceptual Development.* These dimensions allowed the researchers to measure the development of audio senses (audio recognition and discrimination, origin of sounds, direction and following of sounds) and tactile senses (recognition of textures, perception of obstacles).
- *Psychomotor Development*. This dimension allowed researchers to measure motor activities regarding O&M, in addition to navigation through real and virtual spaces.

- *Development of Techniques without Mobility Aides*. This dimension allowed researchers to measure the use of information that can be extracted autonomously from the environment, and which depends on the user's own behavior and the way in which the information is used for mobility.
- *Development of Initial Cane Techniques*. This dimension allowed researchers to measure the learners' skills in using the mobility cane as an aide for navigating through open or closed, real or virtual environments.
- *Development of Concepts, made up of the sub-dimensions Development of Geometric Concepts, Development of Spatial Concepts, Development of Environmental Concepts and Development of Temporal Concepts*. These dimensions allowed the researchers to measure the conceptualization of parameters and concepts needed to attend to and understand instructions, actions and situations within the virtual environment, and later in the real-life environment.

4.2.2 Questionnaire. This is an evaluation instrument made up of five questions: 1) What did you like about today's activities?, 2) What did you NOT like about today's activities?, 3) What was difficult for you to do? Why?, 4) What was easy for you to do? Why?, 5) What did you learn today? The criteria considered for the construction of these questions were: satisfaction with the intervention, which is related to questions 1 and 2; complexity of the intervention, which is related to questions 3 and 4; and learning from the intervention, which is related to question 5.

This questionnaire was administered after each cognitive task solved by the user, by reading the questions to them and recording their responses. The purpose of this instrument was to collect the learners' opinions regarding the experience of their interactions with the videogame interfaces.

4.2.3 Evaluation Guideline for Transfer to the Real World Environment. This is an instrument to support the observation of the activity designed to transfer what was achieved in the virtual experience to the real world environment. In this guideline, the same dimensions from the Evaluation Guidelines for O&M skills were used. However, this guideline is made up of some additional items (44 in total), which were used to evaluate these dimensions on a scale of 0 to 2 points, in which the values for 0, 1 and 2 correspond to the same criteria described in the Evaluation Guidelines for O&M Skills.

This guideline was administered during the observation of the video recordings that were made of all the movements made by each participating user in the corresponding plaza, according to the version of the videogame that they worked with. The *Evaluation Guideline for Transfer to the Real World Environment* served to demonstrate the transfer of the lessons and tasks learned by the users during the virtual interaction with the videogame to their navigation through the real plaza.

4.3 Procedure

Before the intervention with the videogame, the *Evaluation Guidelines for O&M Skills* instrument was administered in order to learn of the initial state of each user's O&M skills. Afterwards, two training tasks were performed during independent work sessions in which each task lasted 45 minutes per learner. In the first training task, the objective was to incorporate the clock orientation system, which is a metaphor utilized within the O&M training skills, and which consists of situating the user within an analogue clock so that directions are associated with the position of the hour hands in which the user turns (see Fig. 3). In this way, if it is desired that the learner move to the right, he is instructed to "turn to 3 o'clock"; if the user is to turn left, he is instructed to "turn to 9 o'clock"; and if it is desired that the user moves backwards, he is instructed to "turn to 6 o'clock".

In the second training task the users interacted with the hardware devices, specifically on exploring and utilizing the Wiimote controller buttons associated with certain actions in the virtual environment. Based on these tasks, an experimental laboratory was implemented in a room, consisting of a laptop computer, two Wiimote controller devices and speakers.

Once the training tasks were performed, the learners performed seven cognitive tasks through the use of the videogame, during seven different 45-minute sessions. Once each of these tasks had been completed, the questionnaire was administered to each learner.

Cognitive tasks 1 and 2 corresponded to the perception of and relation to iconic elements. These tasks consisted of the learners relating the audio and haptic stimuli to actions and/or elements that make up part of the interaction within the videogame, in addition to the use of these clues for moving about through the virtual space. Cognitive tasks 3 and 4 corresponded to the dynamics of the interaction with the videogame. The objective of these tasks was for the learners to establish a temporal-spatial structuring of the virtual environment, and to determine the distances within the virtual plaza regarding the elements that they encounter while navigating.

Cognitive tasks 5, 6 and 7 correspond to navigation activities and the representation of the navigated environments. These tasks were based on the work performed during tasks 1, 2, 3 and 4, with the objective of integrating this knowledge into the planning of navigational routes. After each task, the learners had to represent a mental map of the virtually navigated plaza by using concrete materials (legal blocks and play dough). In this way, the facilitator was able to demonstrate the users' progress regarding their mental constructions of the social environment represented by the videogame.

Afterwards, a work session was performed with the learners in which the O&M skills instrument was administered in order to compare the results obtained before having participated in the intervention with the videogame. In this way, it was possible to evaluate the impact that the videogame had on the users' navigation through the virtual environment.

After finalizing these tasks with the use of the videogame and the evaluation of its impact on the learners' navigation through the virtual world, a cognitive task designed for the transfer of the skills learned virtually to the real world environment was applied (see Fig. 4).

Figure 3. *Training activities.*

Figure 4. *Cognitive task for transfer to from virtual to the real world environment.*

In order to perform this task, the learners were taken to the real world environment corresponding to the plaza that they had navigated virtually in the videogame. Each learner was asked to replicate the movements and routes navigated in the videogame in order to complete the requested missions, according to the mental map of the environment that they had constructed based on their experience interacting with the videogame. Each learner's experience was filmed, recording all of his movements. Once this activity was completed, the questionnaire was applied to each learner.

Afterwards, each of the video recordings was analyzed in order to identify and describe various practices and behaviors, successful performances and difficulties displayed during the movements through the real plaza. To achieve this, the *Evaluation Guideline for Transfer to the Real World Environment* was used to support the observation of the recordings. With this information, three main successfully completed tasks were established for each student, as well as the three main tasks that were the most difficult for each learner.

5. RESULTS

The criteria considered for the construction of the questionnaire were translated into three categories (Satisfaction, Complexity and Learning), used to classify the users' opinions after having performed the Cognitive Tasks. As such, 17 common themes were identified among the opinions, which can be associated with the 3 categories for the classification (see Table 1).

Table 1. *Percentage frequencies for satisfaction, complexity and learning during the intervention.*

Themes	Satisfaction [%]	Complexity [%]	Learning [%]
Looking for the Jewel	48.1	9.6	6.4
Finding the Jewel	18.6	0.0	3.8
Losing	1.0	0.0	0.0
Using the Cane	0.0	1.1	0.0
Turning	17.1	19.3	11.4
Hours on the Clock	37.2	25.7	29.2
Walking	6.2	12.8	10.2
Cardinal Directions	12.4	9.6	54.6
Technology (WiiMote, jacket)	31.0	10.7	11.4
Playing MovaWii	27.9	0.0	6.4
Everything	7.8	0.0	0.0
Nothing	1.6	17.1	3.8
Representing the Map	7.8	0.0	12.7
Bumping into Objects	14.0	5.4	3.8
Numbers	3.1	2.1	7.6
Sounds	6.2	0.0	0.0
Use of the Compass	0.0	1.1	0.0

The students demonstrated great satisfaction with the activities in the videogame, especially looking for the jewel, which is the object used to represent achieving the goal of the videogame (48.1%). Other significant themes for which satisfaction was expressed was the use of the hour hands of the clock as a means for developing the cognitive tasks (37.2%), and the use of the various technologies included in the initiative, such as the Wiimote used as a cane, the jacket with the infrared LED bar, and the use of the buttons on the Wiimote to make decisions (31.0%).

Regarding the elements that were complicated to use (Complexity), the learners displayed a lack of knowledge regarding the hours on the analogue clock (25.7%). As such, the action of "turning" was the second most difficult aspect (19.3%). These two aspects are directly related to the way of using the clock system as a mechanism for spatial location and orientation. The opinion that "nothing" caused any difficulties was expressed in 17.1% of the opinions.

Finally, in the category related to learning, the users valued a set of elements learned throughout the cognitive tasks performed in the intervention. One of these elements corresponds to the cardinal directions (54.6%), which are related to the possibility of identifying North, South, East and West as references for playing the game and navigating when walking. This theme is followed by learning the Hours of the Clock (29.2%), which is related to the use of the clock system for O&M. Finally, there is "Representation of the Map" (12.7%), which corresponds to the capacity to transfer the actions performed in the virtual environment to a physical representation of the desired navigation.

On the other hand, the results obtained from the pretest and posttest, were analyzed using a T-Student test for related samples, for each of the dimensions contained in the instrument utilized (see Table 2).

In comparing the averages obtained for the pretest and the posttest in the differing dimensions analyzed, it was found that the Audio Sensory-Perceptual Development ($t=-3.322$, $p<0.05$), Technique Without Mobility Aides ($t=-4.841$, $p<0.05$), Initial Cane Techniques ($t=-2.629$, $p<0.05$), Geometric Concepts ($t=-3.337$, $p<0.05$), Spatial Concepts ($t=-3.488$, $p<0.05$), Environmental Concepts ($t=-3.107$, $p<0.05$) and Temporal Concepts ($t=-2.517$, $p<0.05$) dimensions presented statistically significant differences, displaying in all cases an increase in the average obtained on the posttest compared to the pretest.

For the Tactile Kinesthetic Sensory-Perceptual Development and Psychomotor Development dimensions, no statistically significant differences were found between the pretest and posttest.

In performing a global analysis regarding O&M skills, an increase in the average of the posttest was found compared to the pretest for the Global O&M Skills indicator ($t=-5.697$, $p<0.05$), and this difference was found to be statistically significant.

The increases in the indicators for which the differences are statistically significant, show that the videogame and its associated activities have an effect on O&M skills.

Table 2. *Summary of the statistical T-Student test results*

Indicator	Mean pretest	Mean posttest	T	p
Audio Sensory-Perceptual Development	1.667	1.883	-3.322	.004
Tactile Kinesthetic Sensory-Perceptual Development	1.825	1.800	.252	.804
Psychomotor Development	1.900	1.936	-.925	.367
Development of Techniques Without Mobility Aides	1.280	1.590	-4.841	.000
Development of Initial Cane Techniques	1.175	1.575	-2.629	.017
Development of Geometric Concepts	1.463	1.738	-3.337	.003
Development of Spatial Concepts	1.530	1.750	-3.488	.002
Development of Environmental Concepts	1.733	2.000	-3.107	.006
Development of Temporal Concepts	1.850	1.933	-2.517	.021
Global O&M Skills	1.602	1.801	-5.697	.000

Based on the statistical results, a more in-depth analysis of the dimensions for which the increases were statistically significant was performed, incorporating the analysis of the video recordings and the data obtained from the evaluation guidelines for transfer from the virtual to the real world environment. The analysis of the video recordings was performed in accordance with two criteria: the performances achieved, or those that the learners executed successfully; and the less-achieved performances, or those that the learners did not perform adequately.

In the Audio Sensory-Perceptual Development dimension, the results of the statistical analysis indicated that throughout the experience with the use of the interfaces defined for the intervention, aspects such as following, direction and discrimination of sounds were improved among the participating students. The analysis of the video recordings showed a transfer of audio sensory-perceptual aspects in the learners' performances during the experience navigating through the real-world plaza, which obtained a 23.5% frequency among the most achieved performances.

The Development of Techniques Without Mobility Aides dimension, which corresponds to the skills that learners use to turn and walk in different directions using the clock system (which is to say, locating and orienting oneself using the hour hands on a clock as a reference), increased significantly after the interaction with the interfaces included in the intervention experience. During the cognitive task for transfer to the real world environment, it was observed that the learners showed some difficulties in performing turns (19.3% of the performances less-achieved). However, the students pointed to a high degree of learning regarding the Cardinal Directions and their use as a means of orientation. This learning emerged as a process of reconceptualization of the use of the 12:00, 3:00, 6:00 and 9:00 hour hand positions as points of reference for North, East, South and West, respectively.

For the Development of Initial Cane Techniques dimension, the statistical analysis showed that the interaction with the interfaces included in the intervention allowed learners to develop and/or improve skills for the use of the cane as a means of mobility. In this way, aspects such as the handle, the position of the arm, movement, navigating and tracking displayed significant progress after having participated in the experience with the videogame. During the cognitive task for transfer from virtual to the real world environment

performed by the learners, it was observed that the use of the cane as a means of tracking and navigating reached a frequency of 11.8% among the most-achieved performances.

Regarding the Concepts Development dimension, the statistical analysis related to the sub-dimension for the Development of Spatial Concepts showed an improvement in the learners' abilities to use the cardinal directions and those related to forward, back, sideways and oblique as references for orientation and navigation. In addition, the results regarding the Development of Geometric Concepts sub-dimension showed an improvement in the learners, related to the comprehension of that which is vertical, horizontal, a curved line, an oblique line, a straight line, a circle, a square and a triangle. Finally, the results related to the Development of Environmental Concepts sub-dimension showed an improvement in the learners regarding the connection of being positioned either along the edge of the environment or in the center, in addition to being able to calculate distances. During the performance of the cognitive tasks for the transfer from the virtual to the real world environment, a higher degree of difficulty was observed related to the transfer of concepts, and especially environmental and some geometric concepts, reaching a frequency of 17.9% of the least achieved performances.

6. CONCLUSIONS

The results demonstrated the creation of a videogame that allows for the development of O&M skills in learners who are blind, in serving as a supportive tool for the construction of a mental map of a virtually navigated space through the integration of its audio and haptic components. In addition, the learners were able to transfer the information obtained for use in the real world environment, where they were able to navigate autonomously and efficiently.

The results obtained regarding O&M skills in users who are blind demonstrated the positive impact of the videogame on such skills. The most significant increases were presented in the Development of Techniques without Mobility Aides dimension, and in the Development of Spatial Concepts sub-dimension. At the beginning of the intervention, these dimensions presented high degrees of difficulty, as they included indicators that required the learning of new content provided by the videogame. The increase in the Spatial Concepts sub-dimension was a result of the hardware support that the videogame provided to the users regarding the ability to establish their positions in space using their own corporality, and understanding that their movements generate changes in space. These changes are manageable and modifiable according to their own spatial needs, directly influencing the orientation that the learners chose when navigating the virtual environment in order to develop each of the requested activities, and to eventually achieve the objective of finding the elements that had been placed within the environment.

Regarding the Tactile Kinesthetic Sensory-Perceptual Development sub-dimension, it is possible to affirm that although the incorporation of hardware elements allowed learners to work on behavior related to this dimension, it is necessary to utilize more training time for such skills based on the establishment and integration of the icons proposed to represent a variety of textures, sensations and shapes of the elements present in the virtual environment.

In relation to the development of psychomotor skills in the learners, the limits of the system (based on its abstract components) made it partially more difficult for the user to be able to integrate the necessary behavior into the experience. The majority of the users were more focused on achieving the actions than the way in which they used their bodies and related psychomotor behaviors, and especially those regarding laterality, which were necessary in order to understand the process that they were participating in.

Finally, regarding the interaction and level of acceptance of the proposed software and hardware that the learners displayed, the majority of the students did not express any discomfort or discontent with the system. In fact, the use of the Wiimote device ended up being a motivating element, in relating it with the use of the cane and in understanding that through this device it was feasible to generate an interaction with the videogame through actions geared towards achieving the proposed objectives of the game. Such actions include generating navigation routes that made it possible to find the hidden jewel in the virtual environment. In the same way, it is necessary to mention that a more prolonged work process with the device would make it possible to use as a cane prototype, given that it was used more as a joystick than as a cane during the observed intervention experiences.

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Appreciating speech through gaming

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ABSTRACT

This paper discusses the Speech and Phoneme Recognition as an Educational Aid for the Deaf and Hearing Impaired (SPREAD) application and the ongoing research on its deployment as a tool for motivating deaf and hearing impaired students to learn and appreciate speech. This application uses the Sphinx-4 voice recognition system to analyze the vocalization of the student and provide prompt feedback on their pronunciation. The packaging of the application as an interactive game aims to provide additional motivation for the deaf and hearing impaired student through visual motivation for them to learn and appreciate speech.

1. INTRODUCTION

Hearing impairment can happen to any child, be it by biological or circumstantial cause. Since speech is learned by children through emulating the sounds that they can hear, people tend to assume that if you cannot hear spoken language, you are unable to learn and use it.

It is a common misconception that the hearing-impaired cannot speak (Schwartz, 1987). In reality, there are some oralists in the deaf community. Through specialized teaching techniques, such as emulating how the mouth and tongue are shaped to produce certain sounds, even deaf people can learn to speak. Children with hearing impairment can, with proper training and early intervention, overcome their difficulties, be taught and aptly trained to speak.

Most of these training techniques, however, require one-to-one interaction between teacher and student, limiting class sizes. A way around this would be through the use of a voice recognition system, in particular the SPHINX-4 (Walker et al, 2004) Hidden Markov Model speech recognition system, to listen and evaluate the speech made by children.

However, some deaf and hearing impaired students choose to stick with sign language, even if speech is being taught in their school. This is influenced by hearing-impaired individuals' belief that speech is for a 'hearing society' (Levy, 1998; Goode 2005). The long and hard training the existing educational system uses to teach speech does not help either. This notion causes the 'deaf society's' further 'isolation' from society (Sadural, 2009).

Those who chose to break out of their stereotype are better able to integrate themselves into mainstream society better than their non-oralist counterparts do. This often results to a better lifestyle and more opportunities in the future (Sadural, 2009).

Speech appreciation, then, plays an important role in this aspect. Simply put, speech appreciation is the clear perception or recognition of the use of speech. Speech appreciation is an unacknowledged factor in a hearing-impaired student’s choice of communication mode. It directly affects the intention of the student to perform the speaking behavior (Sadural, 2009).

In light of these facts, SPREAD (Di et al, 2010), or Speech Phoneme Recognition as an Educational Aid for the Deaf and hearing impaired child, is a gaming application that attempts to provide a mechanism to motivate these children to learn speech. Through a system of visual rewards, the game motivates them to try their best at their training and at the same time enjoy and appreciate speech.

This paper discusses SPREAD and how it aims to provide a mechanism for a hearing impaired child to learn and appreciate speech. The first section gives review of the literature relevant to this research. After the literature review, we discuss SPREAD, in particular its architectural structure and how the child's speech training proceeds with it. In the Results section, we narrate the experience gained with SPREAD's exposure with certain members of the hearing impaired community. We conclude this paper with a sample speech training methodology that incorporates SPREAD.

2. REVIEW OF RELATED LITERATURE

This section is divided into three parts. First, we provide a short background on hearing impairment and short survey on the existing training being given to oralists in the Philippines. Next, we discuss the Theory of Planned Behavior, which shows how the child's attitude towards speech reinforced by speech appreciation can have a strong effect on the desire of a child to learn how to speak. After that, we review another gaming system designed for the hearing impaired child. Lastly, we give a background on the SPHINX-4 voice recognition system, the key component of the SPREAD application.

2.1 Hearing Impairment and Speech Training

Hearing impairment is defined to be a partial or total loss of hearing in one or both ears. Hearing loss can be measured according to the intensity needed for the person to be able to detect the sound.

Deaf children or even children with profound hearing loss will not spontaneously learn how to speak. Even if these children have the full capacity for speech as their vocal cords and other body parts used for speaking are not affected, they simply will not talk for the singular reason that they have never heard speech in the first place.

On the other hand, if the child experienced loss of hearing after he or she has learned how to speak, the speech skill remains throughout adulthood, albeit in most cases the ability to articulate speech sounds degrades over time with lack of feedback on proper pronunciation and communication (Bloodstein 1979).

For hearing individuals, feedback of correct speech patterns occurs automatically as the person can hear the sound he or she makes. For deaf or hearing impaired children, other ways have to be implemented to demonstrate the proper way of speaking. In a typical scenario, hearing impaired children are asked to memorize the necessary mouth formation, tongue position, breathing and throat vibration of the words they are to learn. The children may be grouped so that each may learn from each other, although as the children cannot hear the sounds they make, it is up to the hearing teacher to evaluate their speech. Some teachers use games to further motivate the students. Teachers may reward their wards with star stickers, additional art materials, extra play time, and the like.

Training would begin with the basic vowels then move on to consonant sounds. Simple words are then taught, followed by conversational phrases such as 'How do you do?' or 'Good morning'. As a challenge, students are restricted from using signing to converse with each other. Dyadic communication can still occur, the children would try to speak and they interpret their classmate's speech via their residual hearing and lip reading. Learning the means and the methods of using these different avenues to communicate fall under the total communication paradigm.

Schwartz (1987) defines total communication as the choice of speech and speechreading, sign, fingerspelling and the use of residual hearing depending on the situation. It recognizes the right of every deaf or hearing impaired child to be able to choose whatever means of communication available to him or her in order to communicate. This is the paradigm being followed in most schools in the Philippines, in particular the Philippine School for the Deaf and Miriam College Southeast Asian Institute for the Deaf (SAID).

2.2 Theory of Planned Behavior

The Theory of Planned Behavior (Ajzen 1985, 2002; Ajzen and Fishbein 2005) describes that human action is guided by three kinds of considerations: behavioural beliefs, normative beliefs and control beliefs. Behavioral beliefs describe how an individual links behavior to an outcome. Normative beliefs describe how an individual's family, friends and community react towards a particular behavior. Lastly, control beliefs describe how a perceived factors can improve or impede the performance of a behavior. These three affect the user's intention to perform a particular behavior. Intention, moderated by an external actual behavioral control, then leads to either the performance or avoidance of the targeted behavior.

Let us now discuss the behavior of speech in the hearing impaired context in light of this framework. Behavioral belief would now be the view of how the hearing impaired child sees his or her own ability to speak. However, the difficulty of the speech training itself negatively affects this aspect (Goode, 2005).

For the normative belief, a hearing impaired child is surrounded by a community that deems hearing impairment as a disability. In addition, his or her family has typically low expectation of his or her ability to speak. Finally, the stigma that speech only belongs to the 'hearing society' appears here, leaving the child feeling alienated from his or her hearing impaired peers if the child pursues the speech behavior.

Control beliefs on the other hand can have a positive influence on the speech behavior. A control belief could be the idea that if a child learns how to speak, he or she can communicate not only with his peers but with 'mainstream society' as well. Also, the perception of the use of his or her dormant but natural talents acts as a positive reinforcement as well.

These three beliefs all influence the speech behavior. A child can be made to speak by enhancing the positive aspects of the three belief systems. In addition, the external factor of speech appreciation can boost the desire for speech. One such avenue is through the gaming concept. Having speech training presented as a game would provide an enjoyable learning process. It motivates them to try their best at speech and at the same time to enjoy what they are doing. Figure 1 shows a summary of the Theory of Planned Behaviour for the hearing impaired.

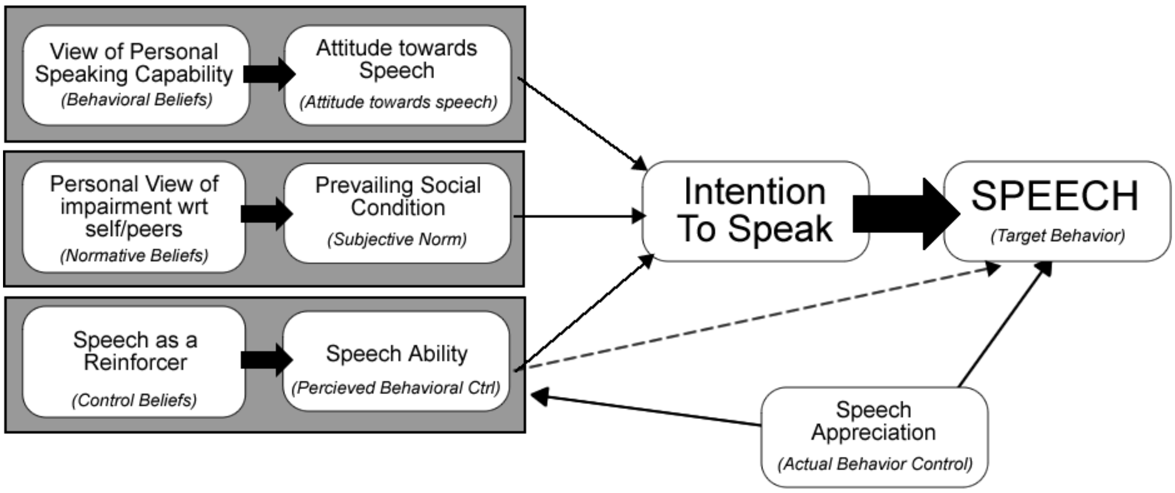

Figure 1. *Theory of Planned Behavoir as applied to the speech behavior for hearing impaired individuals* [Ajzen 1985, 2002; Ajzen and Fishbein 2005; Sadural 2009].

2.3 Speech Training Station and Speech Practice Station

Mahshie (Mahshie et al, 1988) evaluated two computer based speech training systems: the Speech Training Station (STS) and the Speech Practice Station (SPS). The STS gathered not just the utterance of the child via a microphone, but had sensors such as an electroglottograph which detects vocal fold contact and a pneumotachograph which measures average airflow. The SPS is a home version of the STS that just has a microphone as the additional sensors would be too complicated for home use.

Mahshie described the two applications as an attempt to have the child to learn speech through repeated drills of certain speech exercises. For example, the Sustained Duration Game was developed for the child to sustain vocalizations from 1 up to 7 seconds. The child is given on the computer screen an image of a rectangle that only a sustained vocalization matching the parameters of the test would fill up. The Intensity Game shows on the screen a balloon floating next to a vertical bar with three different colors. Blue, at the bottom, indicates that the child's voice intensity is too low. Green, in the middle, indicates intensity is at the required level. The red bar at the top indicates that the voice intensity is too loud. This game will have the student learn how to maintain a particular voice intensity which is a necessary skill for speech.

Despite some technical difficulties (such as accuracy of intensity measurement in the light of background noise and apparent false wrong answers returned by the software), Mahshie has observed that the use of visual aids were very attractive to the children, and these children would even enter the therapy room and use the software even when they are not scheduled for therapy. The children were more willing to work on

speech goals more frequently than they would have using the traditional training methods. With more practise hours being put in, the children were able to meet their speech goals faster than those without access to the software.

2.4 Sphinx-4

Sphinx-4 (Walker et al, 2004) is a Hidden Markov speech recognition system developed by Carnegie Mellon University using the Java programming language. Sphinx-4's creators focused on the core ideas of flexibility and modularity during the development of the system. Each of the major modules of Sphinx-4 can be replaced, allowing researchers to focus on the changes they require while keeping the system in working order.

There are three major components of the Sphinx-4 architecture. These are the front end, the decoder and the knowledge base.

The front end component is responsible for gathering and processing the input data, meaning, the sound clip to be analyzed. This component also extracts the features of the input data which are then fed to the decoder. The front end also has additional features to better process the input data, such as noise cancellation, gain control, end pointing, and Fourier analysis among others.

The knowledge base provides the data needed by the decoder in order to recognize speech. There are three main data sets in the knowledge base. These are the dictionary, the acoustic model and the language model.

The acoustic model is a database of statistical models, with each model representing a single unit of speech. These units of speech are called phonemes. Acoustic models are created by analyzing large collections of speech samples in order to determine what characteristic sound features a particular phoneme has. In essence, the acoustic model maps sound into the basic units of speech.

From this, the dictionary maps a particular combination of phonemes into words, which are used by the decoder to determine what particular word was pronounced. In effect, the dictionary contains the list of words Sphinx-4 is to recognize. The language model describes what word is likely to be spoken in a particular context. This helps the decoder in recognizing words.

The process all comes together in the decoder component. The decoder component accepts the features extracted by the front end. Then, with the information stored in the knowledge base, it processes the data to determine the most likely sequence of words that was inputted into the system.

3. SPREAD

SPREAD (Di et al, 2009) is an application that, from a functional perspective, simply accepts utterances made by a user, passes the utterance to Sphinx-4 for recognition, and then displays the result. We will describe the system architecture of SPREAD in line with a typical use scenario.

The first thing a child sees when using SPREAD is the Flash-based front-end in a web browser. The child will be shown a series of simple words he or she is to pronounce. 'Apple', 'Bat', 'Star' are a sample of such words. Only one word is shown at a time. Words are also grouped into difficulty levels; higher level words can only be accessed upon completion of a lower level. Figure 2 shows the user interface for this section.

Figure 2. *SPREAD main user interface*

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When the child is ready to pronounce the word, he or she must press the RECORD button so that the computer will record the child's attempt. Pressing the button activates the microphone as well as a Java applet which is responsible to recording the child's speech and saving it into a .wav file.

Once recording is done, the Java applet sends the recording over to the server for speech recognition. Once the .wav file arrives at the server, it is passed into the Sphinx-4 recognition engine. The server then compares the recognition result generated by Sphinx and then compares it with the expected result. After determining the appropriate response, the server sends back the result information to the client via the Java applet. The applet then communicates with the Flash front-end to display the result.

A summary of this typical use scenario can be seen in Figure 3.

As stated earlier, SPREAD is a simple application from a functional perspective. However, with the target audience of the application being children with hearing impairment, the user experience must be designed in a way that would motivate the child to learn and appreciate speech. In the course of this work, the user interface, scoring system and the result screen are discovered to be what would make or break the speech training of the child. We will discuss these in the Results section of the paper.

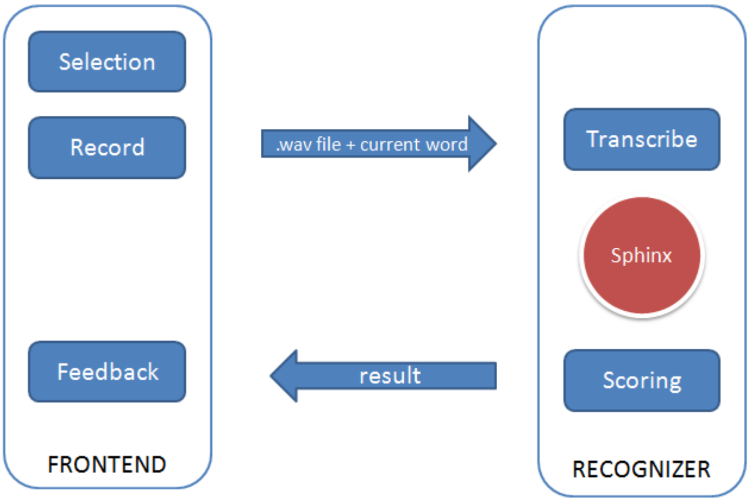

Figure 3. *Functional Diagram of SPREAD.*

4. RESULTS AND DISCUSSION

This section narrates the experiences gained through the exposure of SPREAD with members of the hearing impaired community. Central to this discussion is the need for an improved feedback mechanism that would effectively grade the response of the child.

4.1 Exposure to hearing impaired adults

SPREAD was initially deployed for use with adult members of the deaf and hearing impaired community (Di et al, 2009), in particular, members of the Support and Empower Deaf Children, Inc. The subjects were completely deaf individuals who were not born deaf and are able to vocalize some words.

Initial feedback was very positive; the subjects were very motivated to try out the game and have expressed the wish to have had this application when they were still in school. Successful trials were even met with cheers from the subjects and their audience.

Enthusiasm to the game actually emerged as a problem as well. The excited users could not help but yell into their microphone, distorting the saved waveform data. This is in addition to the cheering audience adding noise to the data. The distorted data was difficult to be recognized by SPREAD, and even though the pronunciation was correct, SPREAD gave a negative result. Strategies to solve this can include automatically adjusting the microphone volume, giving warnings for too loud/noisy environments, or to simply to have a teacher present to guide the student into the proper use of the microphone.

This initial test also showed some urgently needed modifications to SPREAD. The first version of the application simply displayed positive/negative results (i.e. 'You got it!'/'You didn't get it…'). The negative

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results affected the subjects visibly, showing their embarrassment and frustration. A partial scoring mechanism was determined to be a way forward from this situation. This is discussed in a later section.

4.2 *Exposure to hearing impaired children*

SPREAD was next deployed for use in the Special Education (SPED) division of the Batino Elementary School of Quezon City, Philippines. Unlike the adult subjects, the children were hesitant to use the software. Out of the 40 subjects, only 5 volunteered to take part once they were placed in front of the computer. The researchers noted the shyness of most of the students; it took a little bit of coaxing to get even the five to try out the software.

It became apparent that the children did not know some of the words. Although they are able to sign most words, they were only able to speak only the very common words such as 'Car' or 'Star'. The volunteers actually treated the application as a sudden surprise test that they were not prepared for. At the end of the trials, the students were able to recite conversational messages like 'Thank you' and 'Goodbye' better than how they pronounced the words in SPREAD.

This result indicates that the students encountered in this particular test learned speech more for its utilitarian aspect rather than as for casual conversation. Simple greetings only require a limited vocabulary of spoken phrases. In casual conversations, these children opted to use signing rather than memorizing a large vocabulary of spoken words. SPREAD can be modified in the future to test out these short phrases.

There is a need too for SPREAD to be integrated with the existing speech curriculum. The students tested were unprepared for the recitation of the particular words being used by the game. SPREAD would be more effective if the words being shown to the students were just taught by their teacher or as a post lesson evaluation tool.

4.3 *User Interface Design*

The teachers also gave recommendations on the design of the user interface. SPREAD has too many objects in the background image that distracts the student from the word he or she ought to pronounce. It was recommended to reduce the clutter in the user interface to have the student focus on just the word being trained for. Figure 4 shows a simpler user interface.

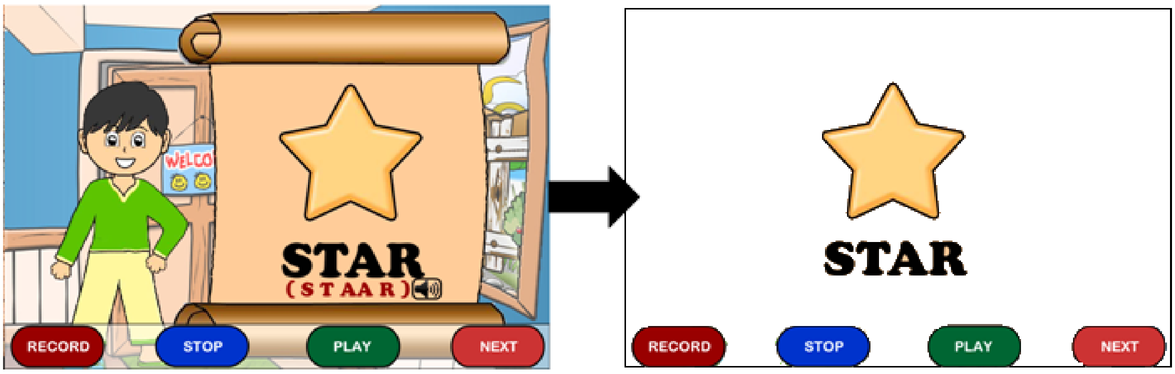

Figure 4. *Proposed simpler interface.*

The feedback screen also needs to be, at the least, reworded. The 'You didn't get it…' message came out as too negative for some of the users, adding to their frustration. It was recommended that instead a 'You can do better!' message or 'Good try!' message would lessen the brunt of a wrong recording session.

4.4 *On Scoring*

To discuss the scoring mechanism of SPREAD, we have to first discuss how Sphinx evaluates sound data. Given the sound file, Sphinx first compares the sound with stored sound samples from the acoustic models. These stored sound samples are called phonemes, which are the basic building blocks of a spoken word. Sphinx actually produces multiple results as it tries to determine which best phoneme combination closely matches the inputted sound.

To help with the evaluation, Sphinx uses a grammar file. This grammar file tells Sphinx what particular words are expected to appear and in what particular combination. This limits the possible outcomes that come out of the decoding process. By default, Sphinx will always produce as an outcome one of the possible words

in the grammar file. After Sphinx produces the best matched word, SPREAD then compares the decoded word with the expected result. If these two do not match, then SPREAD will send a negative result to the front end module.

Unfortunately, this particular scheme does not give partial points. An alternative scoring system was attempted wherein the speech was deciphered at the phoneme level instead of on a word level (Carreon, 2011). The scheme was to provide full points if all the correct phonemes of the word were pronounced correctly, partial points if the 'training phoneme' appears (in contrast to 'training word'), and a negative result if the training phoneme was not detected at all.

This scheme, however, resulted in lower recognition rates. On a per word level, Sphinx can compare the detected phonemes and match it to the closest possible word; this eliminates noise and other ambiguities as the set of possible results is only limited to a few words. The set of possible results expands exponentially on a per phoneme level as Sphinx can no longer get any contextual clues from the grammar file and simply returns any and all phonemes it can detect.

This area is the current focus of the research. The use of the Sphinx confidence score metric seems to be a promising avenue for exploration. A simpler scheme would be to record multiple trials of the same word return how many were detected correctly vs. the total number of trials.

5. CONCLUSION

This paper discussed SPREAD and how it uses gaming as a strategy for motivating a hearing impaired child to learn how to speak. In the course of the research, it was shown that SPREAD can and does promote speech appreciation, though improvements with the user interface and feedback mechanism would have to be addressed in the near future.

Development for SPREAD is still continuing. The end goal for SPREAD is for it to be deployed as a teaching tool working in line with the traditional methodology for teaching speech. It aims only to enhance the learning experience of a child and not to supplant nor to totally replace the need for the standard speech training being done in oralist schools. SPREAD can also be made as a platform for other types of gaming strategies above and beyond this simple object identification scheme. It is hoped that this work will inspire others to explore this promising field of research.

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Helping deaf and hard-of-hearing people by combining augmented reality and speech technologies

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ABSTRACT

Recently, many studies have shown that the Augmented Reality (AR), Automatic Speech Recognition (ASR) and Text-to-Speech Synthesis (TTS) can be used to help people with disabilities. In this paper, we combine these technologies to make a new system, called "ASRAR", for helping deaf people. This system can take a narrator's speech and convert it into a readable text, and show the text directly on AR displays. Since most deaf people are unable to make meaningful sounds, we use a TTS system to make the system more usable for them. The results of testing the system show that its accuracy is over 85 percent, using different ASR engines, in different places. The results of testing TTS engines show that the processing time is less than three seconds and the spelling of correct words is 90 percent. Moreover, the result of a survey shows that more than 80 percent of deaf people are very interested in using the ASRAR system for communication.

1. INTRODUCTION

Today, using new technologies to help people with disabilities is highly regarded and much research in this area is underway. The important issue is how to combine and use these technologies together to make them more applicable. A number of recent studies have shown that AR and VR can be used to help people with disabilities (Lange, et al., 2010) (Zainuddin and Zaman, 2009). AR gives a possibility to disabled people to control and manage the information and adapt it easily to a desired form to improve their interactions with people (Zayed and Sharawy, 2010) (Passig and Eden, 2000). Another technology that can be used to help disabled people is Automatic Speech Recognition (ASR). ASR technology gives the possibility to disabled people to control and use computers by voice commands, e.g., to control robotic arms (Mosbah, 2006). In addition, ASR allows deaf or hard-of-hearing people to participate in conference rooms (Mosbah, 2006). Text-to-Speech Synthesis (TTS) is one of the important systems that is used to help disabled people (Handley, 2009). TTS converts the display information, such as text files or web pages, into the speech for the visually challenged people, such as blind or deaf people (Dutoit, 1997) (Lopez-Ludena, et al., 2011).

Communication with people is a basic need for everyone, but some people are not able to communicate well due to some disabilities. A group of these people is deaf people, and communication is the main problem among them. Deaf people communicate visually and physically rather than audibly. Therefore, they have some problems in their relationship with people. Usually, deaf people use sign-language to communicate with each other, but people have no desire to learn sign-language. For this reason, many people feel awkward or become frustrated trying to communicate with deaf people, especially when no interpreter is available. Besides this problem, most deaf people are unable to make meaningful sounds and also have problems in visual literacy, such as participate in university classes or scientific meetings. Therefore, we tried to find a way to solve the communication problem among deaf and hard-of-hearing people, using new technologies. In this paper, we present a new system, called "ASRAR", for combining AR, ASR and TTS technologies. This is a new system with multiple features, but helping deaf people to communicate with ordinary people is its main goal. Our proposed system uses the narrator's speech to make the speech visible to deaf people on AR display. This system helps deaf people to see what the narrator says, and also the narrator does not need to learn sign-language to communicate with deaf people. Furthermore, deaf people can talk to the narrator, using a computer. The rest of this paper is organized as follows. In Section 2, related work in AR, ASR and TTS area is presented. In Section 3, we explain our proposed system in terms of the structure, system design and system requirements. In Section 4, the experimental results of testing the system are presented, and finally in Section 5, we summarize and conclude the paper.

2. RELATED WORK

Recently, much research has been carried out in AR, ASR and TTS technologies. Some studies have shown that these technologies can be used to help people with disabilities. In the AR field, Zainuddin et al. used AR to make an AR-Book called the "Augmented Reality Book Science in Deaf (AR-SiD)," which contains 3D modeling objects, with using markers and sign-language symbols, to improve the learning process of deaf students (Zainuddin, et al., 2010). Also, in the ASR and TTS fields, Lopez-Ludena et al. developed an advanced speech communication system for deaf people with visual user interface, 3D avatar module and TTS engine to show the effects of using ASR and TTS technologies to help people with disabilities (Lopez-Ludena, et al., 2011). Some researchers have worked on using AR and ASR technologies together. Irawati et al. used a combination of AR and ASR technologies in AR design applications and showed the possibility of using the speech to arrange the virtual objects in virtual environments (Irawati, et al., 2006). Hanlon et al., in a similar work, used the speech interfaces as an attractive solution to the problem of using keyboard and mouse in AR design applications (Hanlon, et al., 2009). Goose et al. sowed that AR and ASR can also be used in AR industrial maintenance applications. They made a multimodal AR interface framework in the SEAR (Speech-Enabled AR) project with a context-sensitive speech dialogue for maintenance technicians to check the factory components (Goose, et al., 2003).

Compared to our work, explained systems are used by speakers, and the speech is used by the system to specify a command to arrange virtual objects in AR environments, or it is used by the system as a parameter to identify objects without using input devices. Furthermore, all the above systems have used AR markers to detect and show virtual objects in an AR environment. Our system captures the narrator's speech and uses the ASR engine to convert the speech to text, so that the AR engine shows the text directly on AR display. In addition, the main user of the ASRAR system is a deaf person that does not talk in the system's scenario, and could use the TTS engine to talk to the narrator. Moreover, the ASRAR is a marker less AR application and uses the narrator's facial expressions as a marker to show the virtual objects in an AR environment.

3. THE PROPOSED SYSTEM

Our proposed system, called "ASRAR", includes a variety of technologies. It consists of two main parts: hardware and software. In hardware part, some hardware requirements, such as camera, microphone, speaker and display, are required, and in software part, we develop the core of the system that consists of the AR, ASR and TTS engines, the Joiner Algorithm and the Auto-Save script. All these parts can be brought together in an integrated system. Figure 1 shows the overall view of the ASRAR with an Ultra Mobile PC (UMPC). Deaf people can also use AR Head Mounted Displays (AR-HMD) or mobile phones to see AR environments. Since the ASRAR is developed as a cross-platform application, it can be used in many portable devices.

Figure 1. *Overall view of the ASRAR system.*

In ASRAR system's scenario, the ASR engine collects the speech from the detected narrator, and the AR engine realizes the scenario. The Joiner Algorithm is used to combine AR and ASR engines to work together. To achieve some goals, it is required to use some automated process scripts that will be integrated to the system in the future. The system uses the ASR engine to recognize the narrator's speech and convert the speech to text. The TTS engine is used by the system to convert the input text into the speech for communication proposes between the deaf person and the narrator. The system also uses the AR engine to display the text as a dynamic object in an AR environment.

To get the video and the speech of the narrator, the ASRAR uses built-in cameras and microphones on UMPC (or mobile phone), or AR-HMD, and to show the objects in an AR environment, it uses UMPC or AR-HMD's display. In addition, the UMPC's keyboard or a virtual keyboard on tablets is used by deaf people to write a text. Then, the TTS engine will convert the text into the speech, and the speech will be played by the speakers. A deaf person can use our system in any place without carrying AR markers because of the following important features in the system.

1. The face detection techniques are used instead of markers to detect the narrator.
2. The TTS engine is used by deaf people to convert the text into the speech.

3.1 System Structure

In this section, we explain the structure of the system and the components that is used in it. In our system's scenario, a deaf person focuses the camera to the narrator. The camera can be a web camera connected to or embedded in a computer or a mobile phone, or mounted on an AR-HMD. The camera captures the video and the built-in or external microphone, captures the narrator's speech, and the speaker plays the text for the narrator. Figure 2 shows the structure of the ASRAR system.

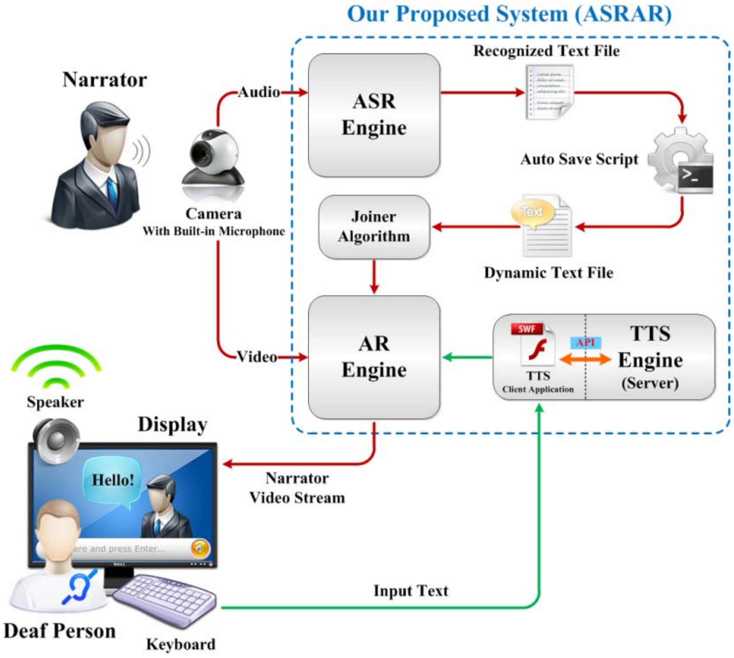

Figure 2. *The ASRAR system structure.*

3.1.1 The ASR Engine. To show the power of the ASRAR and due to experimental work, Dragon Naturally Speaking, Dragon Dictate (Nuance Communications Inc., 2011) and Microsoft Speech Recognition (Microsoft Corp., 2011) are used as powerful external ASR engines. The accuracy of ASR engines depends on their processing and databases, and is usually measured with Word Error Rate (WER) (Mihelic and Zibert, 2008) (Kalra, et al., 2010). The output of ASR engines is the recognized text strings that are written in a text file by the engines. The ASRAR uses the dynamic version of this text file as an input to the Joiner Algorithm. Using the ASR engines, the ASRAR system captures the text strings and writes them respectively in a text file as its text database. For initial testing of the ASRAR, a .TXT file is used by the system to save recognized text strings. On the other hand, the ASRAR can be developed with an internal temporary text array to save the recognized text strings.

Every time the narrator says a word, the ASR engine captures the word in a text file, but the word is not saved in the text file by the engine. The Joiner Algorithm needs the updated version of the text file, which means every word must be saved in the text file. We propose the Auto-Save script to do the saving operation automatically every 1 second when a word is written in the text files by the engine. This script provides the updated version of the text file as "Dynamic Text File." Then, the text file is used by the Joiner Algorithm as the input text, which is shown in Figure 3. The Auto-Save script is a small automated process script that is written with VBScript in Windows Operating System (OS) and with AppleScript in Mac OS. Moreover, it can be developed with other programming languages or as internal coding in the system. To avoid increasing

size of the text file with useless text strings, the ASRAR is programmed to clean the text file completely, every time it is run by the user.

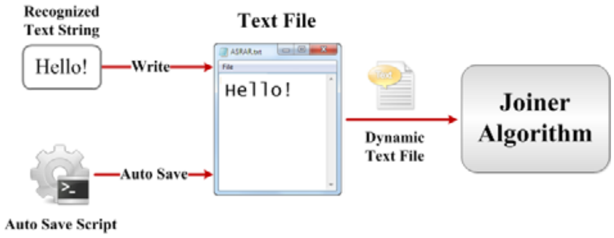

Figure 3. *The Auto-Save script working process.*

3.1.2 The Joiner Algorithm. To make relations between the AR and ASR engines, we propose a module that is called "Joiner Algorithm." The Joiner Algorithm module is a Flash application with AS3 coding (Braunstein, et al., 2007) to load dynamic text strings on a speech bubble image or a subtitle line. The output of the Joiner Algorithm is a .SWF application that is displayed by the AR engine in an AR environment, Figure 4.

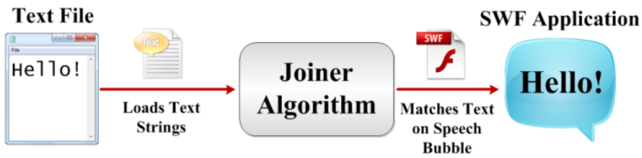

Figure 4. *The Joiner Algorithm working process.*

The Joiner Algorithm is developed to load only the last word in the text file. This development is optional and developers can change it easily to show more words (like a sentence). With this development, the Joiner Algorithm is always looking for the last word in the text file and when it finds a new word, it loads the word on the speech bubble image. In the second development, we change the Joiner Algorithm to load more words (like a sentence) in different styles, such as a subtitle line.

3.1.3 The AR Engine. In the AR engine, the FLARManager (Transmote, 2011) and OpenCV (Open Computer Vision Library by Intel, 2011) (Bradski and Kaehler, 2008) are used. The FLARToolKit library (Spark Project Team, 2011) is also used in the FLARManager framework to make flash supported AR applications, since it is compatible with many 3D frameworks (Hohl, 2008), such as Papervision3D (Hello Enjoy Company, 2011). The FLARManager also supports multiple marker detection (Cawood and Falia, 2008) (Arusoaie, et al., 2010) that will enable us to develop the system in the future for detecting more than one narrator in the environment. The purpose of using these toolkits is for their availability to export the system as .SWF, hence allow the availability of making the system cross-platform. Our system uses the face detection instead of the marker. If the marker had been used in the ASRAR, we should have designed specific markers, and the users should have carried the marker. Therefore, the ASRAR is developed as a marker-less AR application. In this case, some marker detection challenges, such as marker choice and marker creation that makes the system more complex, are avoided. We found a ported version of OpenCV for AS3 called "Marilena Object Detection" (Spark Project Team, 2011) for facial recognition, object detection and motion tracking. It has the best performance among AS3 libraries for face detection, and doesn't have a heavy process in the AR engine. The Marilena library is combined to the FLARToolkit library to develop the AR engine with Adobe Flash Builder IDE (Adobe System Inc., 2011). The block diagram of AR engine is shown in Figure 5.

In the AR engine, after the narrator's video frames are captured by the camera, the face detection module identifies the face of the current narrator, and sends this information to the Position and Orientation module. For initial testing of the ASRAR, the face detection module is developed to detect and use only the face of one person as the narrator's face. In this method, the ASRAR knows where the narrator's face is located in the video frames. Simultaneously, the Joiner Algorithm sends its output, which is a .SWF file, to the Position and Orientation module. Then, the Position and Orientation module places the speech bubble .SWF file to the narrator's face information, and sends it to the Render module. Finally, the Render module augments the output of the Position and Orientation module on AR display, near the narrator's face. It also renders the TTS client application at a fixed position in AR environments. Figure 6 shows the narrator's speech and the TTS client application that are visible in an AR environment.

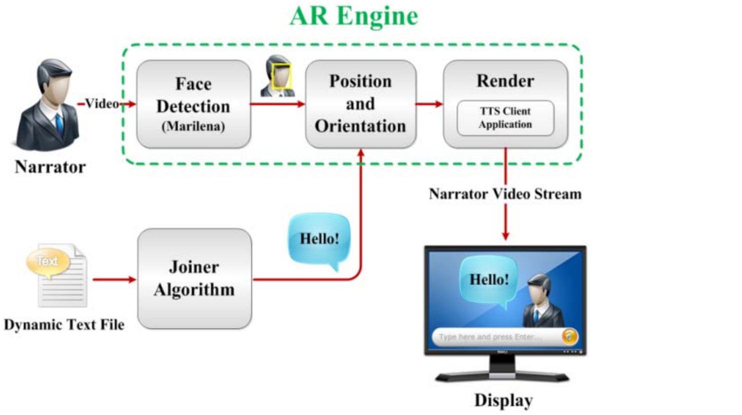

Figure 5. *Block diagram of the AR engine.*

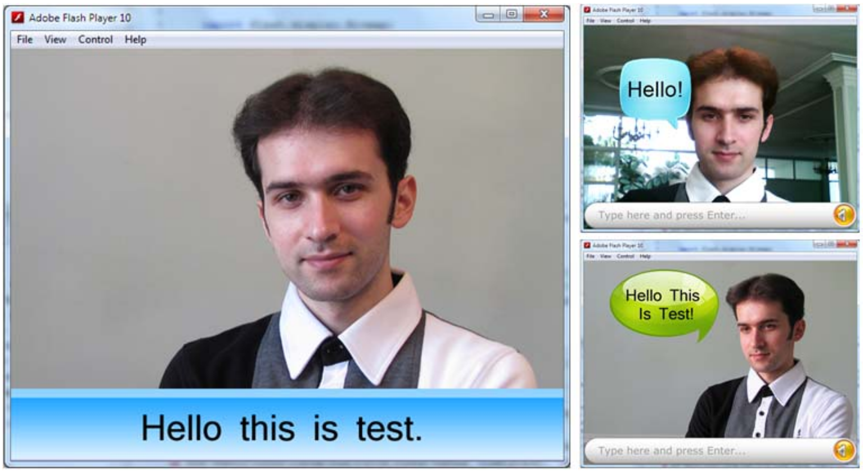

Figure 6. *Different text style's view in the ASRAR system.*

The speech bubble, which is accommodated near the narrator's face, is sensitive to the narrator movements and when the narrator moves, the speech bubble also moves smoothly. In addition, it is zoomed in or out without any delay, when the narrator moves forward or backward. It is possible to make the speech bubble sensitive to the narrator's face rotations, but we disable this feature by default, since the text is faded and become unreadable with rotating the speech bubble. This problem will be fixed if we use a subtitle style. For the initial testing of the ASRAR, the user cannot select the text style's appearance in AR environments.

3.1.4 The TTS Engine. In the ASRAR system, the TTS engine has two main parts: the TTS client application and the TTS engine server. The TTS client application is a small Flash application that is connected to the TTS engine server by APIs, and is added to AR environments by the AR engine. Figure 7 illustrates the TTS client application structure. For initial testing of the TTS engine, the user must connect the system to the internet to be able to connect the TTS engine client application to the TTS engine server, using the TTS engine's APIs.

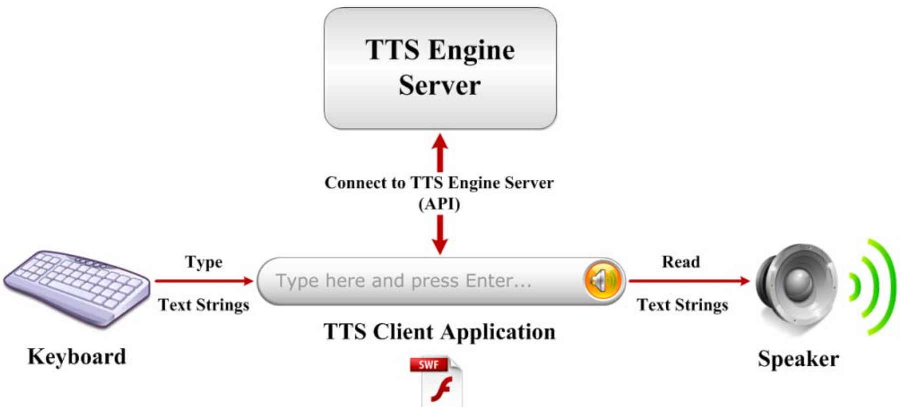

Figure 7. *The TTS client application working process.*

When the narrator says something, the deaf person can write a text and reply using the UMPC's keyboard or virtual keyboard on tablets. This text will be played by the speakers when the Enter key is pressed by the deaf person. This conversation is removed automatically by the system to make the system ready for the next conversation.

3.2 Hardware Requirements

To run the ASRAR in the basic state, it is not necessary to have very powerful hardware specifications. Generally, we need some specific hardware requirements to run the ASRAR in a portable device with Windows OS. These hardware requirements are shown in Table 1.

Table 1. *Hardware Requirements.*

Device	Description
Processor	Intel Mobile or Core Due 1.0 GHz.
Memory	1 GB.
Camera	640*480 VGA sensor or more, compatible with USB 2.0 or 1.1, or built-in cameras.
Microphone	All types of built-in or external microphone.

The power of ASR engines is different in portable devices and depends on hardware specifications (Mihelic and Zibert, 2008). Nevertheless, the ASRAR is run easily on new mobile phones, due to recent advances in mobile hardware. For initial testing of the ASRAR in Windows and Mac OSs, we use an UMPC and a MacBook Air with specific hardware, such as Intel processors, 4GB memory, and 5mp web camera with noise-cancelling microphone. The ASRAR and also the external ASR engines work fine with this particular hardware and provide very good results.

4. EVALUATION RESULTS

We evaluated and tested the ASRAR in four different noisy environments, using three popular and powerful ASR engines. In addition, two online powerful TTS engine servers, such as the Google (Google Android Developers, 2011) and the demo version of AT&T (AT&T, 2011), are used to test the TTS engine. We classified our tests according to different conditions that a deaf person might be. It is tried to choose a condition that reflects the performance of the ASRAR in terms of word error rate and recognition accuracy. To get better results, an external microphone with a noise-cancelling feature and a powerful digital camera are used to capture the narrator's video. Also, it is assumed that the distance between the narrator and the camera is only 1 meter, and the narrator speaks slowly with a clear English accent.

4.1 Classification of the System Tests

To test the ASRAR, the tests are classified to: Test 1 for ideal ASR engine, Test 2 for ideal narrator, Test 3 for ideal environment and Test 4 for crowded environment. In Test 1, we used a writer script, which was developed with VBScript programming language, instead of the ASR engine to write some words directly into the system's text file at the specific times. Therefore, this test did not have any phonetic problem and noise in the system. We did this particular test to know the effects of working the ASR engine in 100 percent performance on the system. For initial testing of the ASRAR, the writer script was developed to write some words automatically every two seconds in the text file. This script worked like a narrator says words every two seconds, and the ASR engine writes these words in the text file.

In Test 2, we used the transcription feature in the ASR engines to transcribe a clear recorded man's audio file into the ASRAR's text file. Transcription is the ability of ASR engine to get the audio file of the speech and convert the audio file to text strings (Mihelic and Zibert, 2008). The transcription process needs to open and read recorded audio file to perform, so there are some delay in it. However, this delay is not important in the ASRAR because it is due to some processes in ASR engine. Of course in a real environment we do not use a recorded speech audio file and transcription process. Nevertheless, we will see acceptable results on average if the transcription feature is used. Dragon Naturally Speaking and Dragon Dictate have the ability to open recorded audio files and transcribe them to text strings, but Microsoft Speech Recognition does not have this ability in built-in free version on Windows OS. For transcribe our audio file with Microsoft Speech Recognition, we used internal playback of the audio file with the audio player software, and then Microsoft Speech Recognition converted the audio file to text strings.

In Test 3, we tested the ASRAR in a closed environment with very little noise, such as a home room or a personal office, and it is assumed that the narrator speaks slowly and loudly with clear English accent. In addition, to get better results, we assumed that the distance between the narrator and the camera (with microphone) is only 1 meter. Finally, In Test 4, we tested the ASRAR in a crowded environment with much noise to obtain the better performance results. In this test, the ASRAR was used in an outdoor environment with more noise.

4.1.1 Comparison of the Tests Result. We tested and compared the results of the four different tests with three popular and powerful ASR engines, which were the Dragon Naturally Speaking, the Dragon Dictate, and the Microsoft Speech Recognition. Each of these ASR engines has features that make them different from each other. The ASRAR is a cross-platform system, so we tested it in different operating systems by using different external ASR engines. The Dragon Naturally Speaking is a very powerful ASR engine that gives more features rather than other ASR engines. It provides impressive speech recognition and transcription abilities, and is surprisingly quick and accurate. The Microsoft Speech Recognition is a built-in speech recognition tool that the Microsoft included it free in Windows Vista and Windows 7 OSs. The features and accuracy of the Microsoft Speech Recognition certainly make it more useful. The Dragon Dictate is another speech recognition software that developed by Nuance Communications for using in Apple Macintosh OS. The result of our tests shows the performance of the ASR engines in different conditions, and it also reflects the performance of using the system in different places with very good approximation. For each of the tests, we considered the different environmental conditions, but these conditions were identical to each ASR engine. It is very important for us to know whether or not the system can work in different environments in terms of performance and recognition accuracy. The results in Figure 8 show that the recognition accuracy of the Dragon Naturally Speaking is 90 percent on average compared to other ASR engines. These results also show that the accuracy of the system is over 85 percent on average, using different ASR engines in different noisy environments. Therefore, Figure 8 shows that this system can be very useful for helping deaf people in different noisy places.

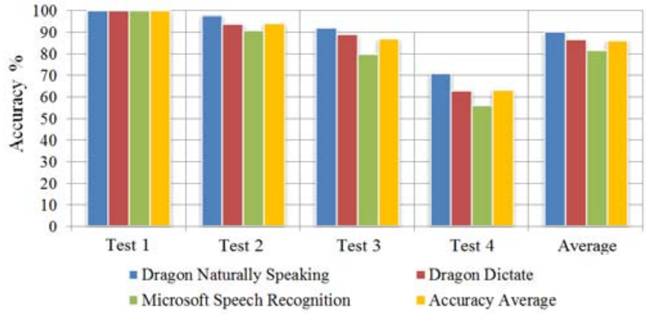

Figure 8. *Comparison results of testing the ASRAR system in different environments.*

4.2 Testing the TTS Engine

To test the TTS engine, two online powerful TTS engine servers, such as the AT&T (demo version) and the Google, are used. The Google TTS engine server contains only a female speaker, whereas the AT&T database consists of male and female speakers with different English accents, such as British and American. We evaluated the results for 10 random words, in terms of engine processing time, voice quality and percentage of spelling correct words in unpredictable sentences. Figure 9 illustrates the results of the AT&T and the Google TTS engine servers. Figure 9 (a) shows that the Google and the AT&T on-line TTS engine servers have very fast response time, and the average processing time is less than three seconds using 128 Kbps ADSL internet connection that is a reasonable result for on-line TTS engines. Of course, the speed of typing words by a deaf person is important, but we assumed that this time is two seconds for each word. Figure 9 (b) shows the voice quality of the Google and the AT&T TTS engine servers. In this test, numbers zero to 10 are used to rank voice quality, where number 10 shows that the speech is completely recognizable, and number zero shows that the speech is unrecognizable. It is noted that the voice quality is above 8, which is very close to natural speaking. Figure 9 (c) also shows the percentage of spelling correct word in unpredictable sentences. It is clear from Figure 9 (c) that the average spelling correct word is above 90 percent that is very reliable for powerful TTS engines.

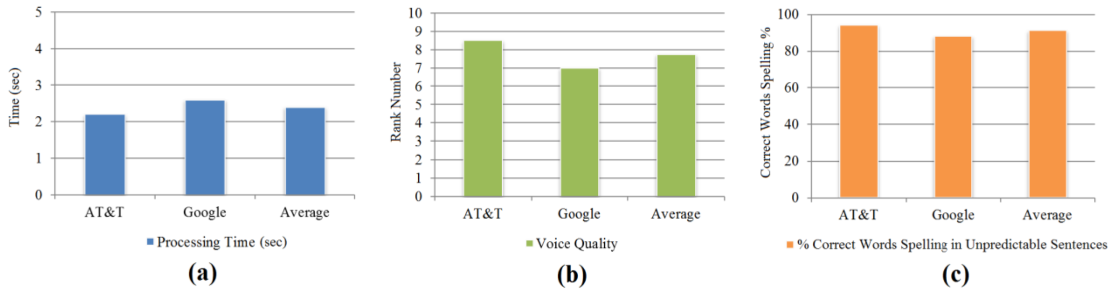

Figure 9. *The results of testing TTS engines in the ASRAR system.*

4.3 Processing Time of the System

It is assumed that the system works in real-time, which means every time the text file is changed by the ASR engine the results appear immediately on AR display. Thus, the processing time of word recognition and displaying it on AR display depend directly on the power of the ASR engine and hardware specifications. Figure 10 shows the processing time of the system in four different steps. In each step, a random word was captured and recognized by the ASR engine.

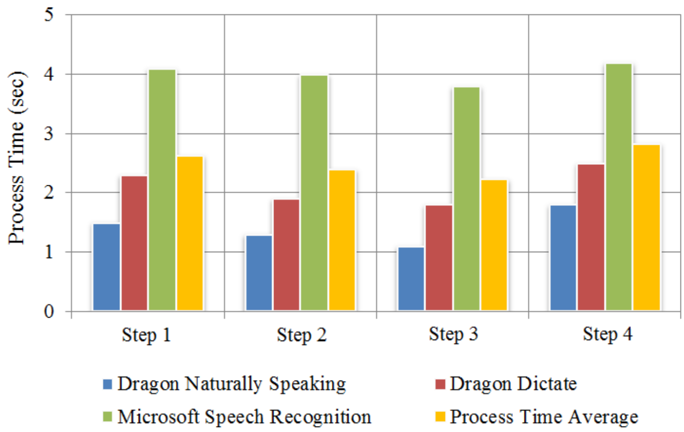

Figure 10. *The processing time of the ASR engines, with average.*

It can be noted from Figure 10 that the average processing time of the different ASR engines is less than three seconds that is not good enough, but it is reasonable for initial testing of the system. The processing time will reduce if we use the more powerful ASR engines.

4.4 Survey about the System

In this paper, we conducted a survey among 100 deaf people and 100 ordinary people to understand the interest rate of using different communication methods between them. The following question helped us to clarify our objectives for the survey: "Will you intend to use such our system for communication in the future?" The communication methods in this survey are assigned as Text, Sign-language and the ASRAR (AR+ASR). Since we did not have the necessary hardware (such as AR-HMD) to implement the system, people were not being able to test the ASRAR. Therefore, the survey was only conducted as questionnaires and people could choose different answers simultaneously. In addition, we provided a manual file of the system to make deaf people familiar with the ASRAR system, which contains the ASRAR structure and working process with images of the system. The result of this survey is presented in Figure 11.

The results in Figure 11 show that more than 90 percent of both groups are interested in using the ASRAR system to communicate with each other, instead of using only text or just sign-language. It is noted from Figure 11 that more than 80 percent of deaf people and less than 30 percent of ordinary people prefer to use sign-language. Also, these results show that deaf people and ordinary people have problems to communicate with each other, using only sign-language. Therefore, the ASRAR can be useful to solve the communication problem between deaf and ordinary people.

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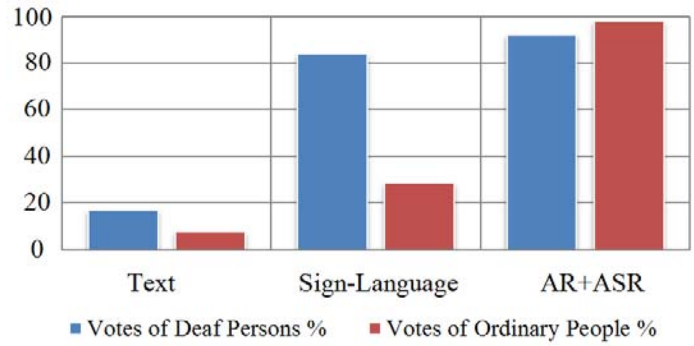

Figure 11. *Interest rate of three separate communication methods between deaf and ordinary people.*

5. CONCLUSIONS

This paper proposed a new system, called "ASRAR", to help deaf people to communicate with people and vice versa, by finding a common factor between AR and ASR technology, which is the text string. The common factor helped us to combine AR and ASR technologies. Our proposed system makes the speech visible to deaf people on AR display. The comparison of the ASRAR system's accuracy in different tests showed that the system is consistent and provides acceptable results with current new ASR engines. The results of testing the ASRAR in the different environments showed that this system acts very well in many situations that a deaf person might be and provides acceptable results with current ASR engines.

The results of processing time of the ASRAR indicated that the average processing time of word recognition and displaying it on AR display is less than three seconds, using today ASR engines, which is reasonable for these engines. Moreover, two powerful TTS engines were added to the system to convert the text into the speech. The results of testing online TTS engine servers, such as the Google and the demo version of AT&T, showed that the response time and the average processing time is less than three seconds. The results also showed that the voice quality is very close to natural speaking.

A survey was also conducted to know the usability of this particular system between deaf people. The results of the survey showed that almost all deaf people will use our proposed system as an assistant to communicate with ordinary people in the future. In this paper, we showed that AR, ASR and TTS technologies have a high potential to combine and advance. Therefore, these technologies are in a position to grow and offer new possibilities to the world of technology. Hopefully, our proposed system will be an alternative tool for deaf people to improve their communication skills.

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Evaluation of the prototype mobile phone app *Pugh*: a 3D cartoon character designed to help deaf children to speech read

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ABSTRACT

Pugh, a 3D cartoon character, is a prototype smartphone application developed at the University of Salford. Its purpose is to provide speech-reading exercises for hard of hearing and deaf children. This paper discusses the design of the application, the test process and acknowledges that the technological limitations of the platform and the character's non-human characteristics provide some interesting challenges. A preliminary test was conducted to evaluate speech perception and lipreading from *Pugh.* The findings proved that *Pugh* is not an accurate speaker. Further development of the lip movement and facial expressions is required in order to achieve accuracy.

1. INTRODUCTION

Pugh, a 3D cartoon character, features in a mobile phone application for iPhone/iPod/iPad that aims to provide speech-reading exercises for hard of hearing and deaf children in the United Kingdom. The application is a prototype that we developed at the University of Salford, UK, with the view to expand the ways in which technology can be used to facilitate the learning process of speech perception. At the beginning of 2012 there were more than 570,000 applications available for Apple products alone, therefore the idea to develop this prototype educational software as an iPhone app seemed appropriate. This type of platform, which provides visual, auditory and vibro-tactile sensory feedback, offers the opportunity to develop educational material that could be inclusive to people with disabilities and reach a wider audience.

The application prompts users to type in text and *Pugh* will speak the words, with sound or without (Fig. 1). The speed at which he speaks can be adjusted to facilitate lip reading. The users can also change the perspective view. Our main research questions are whether the current prototype of *Pugh* could effectively imitate the qualities of a human speaker and whether the application could be used in speech-reading exercises? Due to its existing non-human design *Pugh* can only replicate the most prominent lip movements. Phoneticians have classified the features of speech into three main categories, depending upon the emphasis that is given to the event (Harley, 2000):

1. The articulatory phonetics, which study how speech is produced
2. The auditory/perceptual phonetics, which study how sound is perceived and
3. The acoustic phonetics, which focus on acoustic and physical characteristics of sound.

Although all three categories are important in order to provide an accurate evaluation of *Pugh*, this study gives more emphasis on the articulatory phonetics of the speaker (*Pugh*), and the auditory/ perceptual phonetics of the listener (the user of the application). Even though the present programming of *Pugh* has some limitations, as the iPod touch graphics did not allow for the addition of enough skeleton bones in the 3D geometry mesh, it seemed crucial at this stage of the development to examine and to identify the accuracies and inaccuracies of the avatar's lip movements.

This paper describes the development of the application and the design of the speech-reading test, it presents and discusses the findings of the preliminary evaluation and proposes a plan for future work.

Figure 1. *A screenshot of Pugh as he appears in the iPhone application.*

2. THE CONCEPT OF PUGH'S DESIGN

Many experiments and investigations have been conducted to evaluate the effectiveness of audiovisual techniques for developing deaf children's speech-reading ability. Computer-based instruction is emerging as a prevalent method to train and develop vocabulary knowledge for both native and second-language learners (Druin & Hendler, 2000) and individuals with special needs (Adamo-Villani & Wright, 2007; Adamo-Villani, 2006; Barker, 2003). Withrow (1965) supports that the use of 2D motion pictures can extend the speech-reading and auditory stimuli of a deaf child and reinforce the ability to produce speech. Saleh (1965) has proved that the use of a 2D image and 2D motion pictures can increase up to 50% the comprehension of the environment and the speech perception of a child. Although many experiments have proven that the proper use of 2D images and animation can enhance the speech-reading ability of deaf children, the use of the 3D visuals has not yet been thoroughly investigated. Massaro (2006; 2003) by creating *Baldi*, a realistic 3D human head, proved that a 3D avatar can be used for speech perception. *Baldi* is a computer animated tutor that uses accurate visual and audible speech for language and vocabulary learning **(**Animated Speech Corporation, 2006) which has also been released as an iphone application (Psyentific Mind Inc. 2012). The *Baldi* head has a human structure therefore the mapping of accurate facial and lip movements was easier to achieve using motion capture data from a real person. Although *Baldi* has been developed with all ages in mind, a realistic floating head might not be very appealing to young children. The rationale for developing a cartoon character such as *Pugh* was to cater for this younger audience.

Pugh is a cartoon type fictional character, designed to appeal to children between the ages of 4-10 years old. *Pugh's* face and body are not human, which presents further complications and difficulties in making it an accurate speaker. The challenge of this study is to develop a non-human character, which could be as accurate a speaker as *Baldi*. The idea of children engaging and interacting with a 'friendly' character is a concept that *Pugh* has been modelled on. Therefore the creation of a believable character was important for this application to engage with children. *Pugh* has been designed with eyes on storks so that he can add expression to the words that he is saying. Believability does not require human form and this is suggested by characters such as Bambi. It is shown even more strongly by the character of the Flying Carpet in the Disney animated film *Aladdin* (1992). Moreover, the application allows the user to interact with *Pugh* which adds an important aspect to the learning process. Goldin-Meadow and Singer (2003) discuss how deaf children learn more by using their fingers than their mouths and ears. This notion of the deaf learning through touch inspired the interactions programmed in this application. The mobile phone and tablet platform was chosen because it provides this type of interactions. Applications that feature talking cartoon animals have been developed by Out Fit 7 Ltd. (2012; 2010) but these have been mainly created for entertainment and not for educational purposes hence the characters are not accurate speakers yet they are engaging and fun to interact with. The objective of this project is to create a character that combines both.

3. THE DEVELOPMENT OF THE APPLICATION

3.1 The 3D Model of Pugh

A polygonal 3D geometry mesh was built using Autodesk Maya based on an initial clay model of *Pugh*. Care was taken to keep the number of polygons as low as possible, as the application's target platform only offered low graphics performance. The mouth area was designed to have a higher density of vertices in order to reduce artefacts when animating the lips. A skeleton rig was created for the lips area while a basic skeleton was added for the arms, fingers and legs. The lips had bones in the corners, four at the top and four at the bottom. We additionally placed bones for the cheeks, chin and under the nose for reference and to animate facial expressions (Fig. 2).

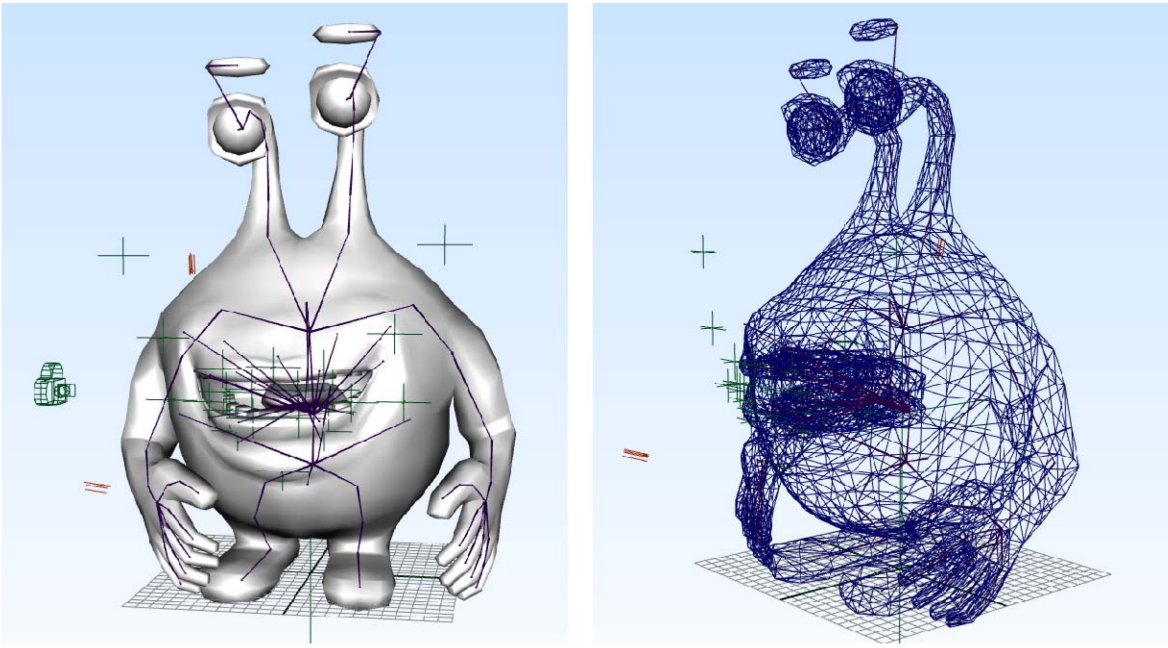

Figure 2. *Screenshots of Pugh's 3D model, shaded and wireframe.*

3.2 Motion Tracking and Animation

To capture the lip movements of a human speaker we utilised an optical marker-based motion tracking system by Vicon with six cameras (Fig. 3). The markers were placed at the same positions as the bone control points in the skeleton rig of the 3D model. Each marker was a reflective sphere with 5mm radius. With this marker size, the tracking system offered an accuracy of approximately 2-5mm. We captured several sequences of reading out a list of words, each emphasising one of the 44 phonemes of the English phonetic alphabet chart. Additionally, we captured video footage as reference material for evaluating the mouth movement of the 3D model and for animating the tongue.

When the prototype application was developed, the iPhone 3GS had just been introduced but the iPhone 2 was still widely spread; hence a requirement was that the app would run on devices starting from iPhone 2. This generation, however, only supported the OpenGL ES 1.1 graphics standard, allowing a maximum number of nine bones per mesh. Including the mouth, eye brows, arms, legs and fingers, *Pugh*'s skeleton had more than 100 bones. Although the mesh could have been separated into smaller patches, each controlled by nine bones maximum, this would have created unrealistic hard edges at the seams of the mesh patches when animating the mesh. As a consequence, we decided not to implement a skeleton based animation so we used the traditional morphing method instead, where the geometry is animated by interpolating vertex positions between meshes that represent certain poses of *Pugh* while articulating. An advantage of this method is that the poses could be tuned on a finer granularity than what would have been possible with the skeleton method. For example, skin and wrinkles could be sculpted in more detail and independently, where neighbouring bones might have influenced each other. The disadvantage is that subtle movements from motion tracking could get lost due to the linear interpolation between selected poses. Hence, a large number of intermediate poses were necessary to guarantee enough detail, which in turn increased memory consumption on the mobile device.

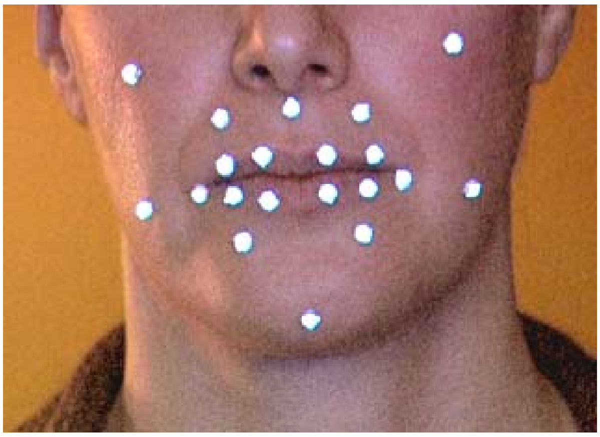

Figure 3. *Arrangement of reflective markers on a subject.*

For the prototype application, we created poses for nine visemes (visual phonemes). These included /a/, /e/, /f/, /k/, /l/, /m/, /o/, /sh/ and /t/. All occurring phonemes were mapped to one of these visemes based on similarity, for example phonemes ‘ae’, ‘er’ and ‘hh’ would use the viseme /a/, or phonemes ‘m’, ‘b’ and ‘p’ would use the viseme /m/. We also created a few additional poses used in animation sequences when *Pugh* is idle and not speaking in order to make him more life-like and show random movements, such as looking around, yawning or scratching himself. Our system allowed blending of several morph targets within one animation sequence so that ‘speaking’ poses could be mixed with idle poses to achieve a natural impression.

3.3 Simulation Environment

The simulation environment of the application was implemented using the Oolong Engine. Oolong bundles a set of C++ libraries helping to develop and port games to iOS based mobile devices. It provides a run-time framework with access to the graphics system, math functions, file format utilities and touch screen. On initialisation, the application loads the geometry and texture files for the displayed scene. It then allocates the required memory and prepares the morph targets by registering a number of vertex buffer objects. The simulation loop continuously reads user input and triggers the respective actions. It also advances the simulation time, switches between poses and controls the blending weight for animation.

The speech audio output was generated using the *Flite* library, a run-time speech synthesis engine developed at Carnegie Mellon University (Black & Lenzo, 2009). It analyses a sentence and creates a set of keys representing the phonemes in the words of the sentence. For example, the word ‘hello’ produces the phoneme keys ‘pau’, ‘hh’, ‘ah’, ‘l’, ‘ow’ and ‘pau’. Based on this set of phonemes, an audio file is synthesised and stored on the file system. This audio file is then played back when *Pugh* speaks and audio output is enabled by the user. The set of phonemes is also used to select the respective visemes for lip animation. Synchronisation of the audio output and lip animation was achieved by controlling the blending time between visemes to match the individual phoneme timings extracted from additional phoneme information provided by *Flite*.

The user interface was implemented using the standard tools of Xcode for iOS development. The application shows a splash screen when loading and provides a separate help page with instructions. The main screen shows the 3D graphics window in full-screen with *Pugh* centred standing on a planet-like surface. A text bubble above *Pugh* and control buttons at the right and bottom of the screen are displayed as overlay icons, allowing the user to enter text, show/hide the text bubble, replay speech output, and to adjust the speed of the animation. The perspective and zoom can be controlled via the typical two-finger gestures. Tapping on him would trigger one of three short animation and sound sequences (e.g. a response to a tickle).

4. PRELIMINARY EVALUATION AND FINDINGS

4.1 Design of the Speech-reading Test

Campbell and Mohammed (2010) survey of 52 lipreading tests, as well as other tests that examine the lipreading skill from a clinical and neuropsychological perspective (Mohammed et al. 2006) have been consulted in order to design a subjective experiment for the preliminary evaluation of the application. Taking into account *Pugh's* initial limitations it was deemed rational to design a short test that would examine the lip accuracies and inaccuracies only for the easy consonants and vowels. The test followed some basic

guidelines as proposed by Markides (1980), thus it consisted of five visible consonants (p, b, m, f, v) and five vowels (a, e, i, o b) in VCV, CVC, CV, VC words, 15 high frequency words (primary school level) and three sentences.

4.2 Participants

Originally the test was designed to be performed by deaf pupils of secondary or further education UK schools which teach oral communication but because *Pugh* is a prototype and hence unfamiliar to many users, it was considered important to use adult experienced speech readers for this initial test. Based on Bernstein et al. (1998) work, deaf are considered the best speech readers. To create an accurate test the participants had to present a homogeny in their characteristics: a) They had to be over the age of 12 years old in order to have a cognitive knowledge of the vocabulary and some years of experience with speechreading b) To have some level of hearing loss (profound or severe) in order for sound to be tested as well c) Oral communication to be their primary means of communication d) English to be their mother tongue or English to be their dominant language e) know how to speechread or be relevant to purpose of the test (phoneticians, speech therapists, linguists, etc.

An online test was created in order to reach more participants. This contained 37 videos captured from an iPhone’s screen showing the character speaking the predefined words. From the six participants who performed the test two were deaf. Their responses are discussed below.

4.2 Findings

The secondary research on phonetics, speech-reading and existing learning resources for hearing impaired children, in conjunction with the findings of the preliminary subjective test, demonstrated that, at the moment, *Pugh* is not an accurate speaker. Due to the low number of participants, a statistical analysis could not be achieved by combing all the above information and by analysing the results of the tests, there is strong evidence that speechreading from the existing version of *Pugh* is very difficult. We applied the recommendations as published by Bernstein et al. (2010), Dodd (1980), Markides (1980), Jeffers and Barley (1980) for scoring and analysing the responses. For the first three parts of the test (VCV, CVC, CV, VC) a sufficient proportion of the speechreading of the consonants was correct. The responses giving a consonant of the same viseme class cannot be considered as a mistake. The inaccuracies caused by the limitations in the technology to animate *Pugh*’s lips more accurately, are also confirmed by the fourth part of the test (vowels) as seen in Table 1. *Pugh* cannot articulate the vowel ‘o’, thus the inaccurate responses of the participants cannot be considered as a mistake of speech perception. The consonant ‘p’ was chosen to be the stable variance, because *Pugh* can articulate this phoneme accurately. The vowel ‘a’ was perceived correctly by all the participants.

Table 1. *Participants’ responses to Part 4 of the online test (vowels)*

Part 4	**Syllables**	**Subject 1**	**Subject 2**	**Subject 3**	**Subject 4**	**Subject 5**
Vowels	CVC syllables C = P	Normal hearing	Normal hearing	Normal hearing	Deaf/Severe level of hearing loss	Deaf/Severe level of hearing loss
The participants had to lip-read the Vowel in the middle of the CVC syllable.	PAP	A	A	A	A	A
	PEP	E	I	A	I	E
	POP	A	A	I	E	O
	PIP	A	I	A	U	I

Furthermore, the incorrect responses for the fifth part and the sixth part of the test (words and sentences), confirm that the animation of the lips and tongue require further development. However, there was a great proportion correct of the bilabial phonemes and the labiodental phoneme ‘f’, which was perceived correctly by all the participants. The word ‘baby’ was perceived correct by all of the participants. Researchers have stressed speechreading perception could be more accurate when the observer is aware of the theme. The fact that words were presented without any indication has caused confusion to the speech perception. It would have been more suitable if some indication was provided for each word. This could be achieved by

presenting all the words, and the sentences, inside a story (e.g. *"Mary and John got married and had a 'baby').* Another way of offering a hint about the words is by using categories (e.g. list of vegetables, list of colours, list of numbers and so on).

This investigation helped us to understand and identify the weaknesses of the animated character and how we could make *Pugh* an accurate speaker by improving its lip, facial and body gestures. The test gave us a clear indication of which vowels, consonants and words *Pugh* can or cannot articulate well. Also, the avatar's idle position seemed to confuse the users as *Pugh* is closing his mouth too quickly after completing a word, which visually adds a bilabial closure at the end, causing the assumption that some words ended with m, b or p. In addition, the facial characteristics of *Pugh*, the eyes, eyebrows, cheeks, which are not programmed to match human expressions, result in an expressionless face which requires the observer to use only the lip movements for speech perception. Additionally, at the moment *Pugh* cannot include the suprasegmental characteristics of language such as intonation and stress, therefore it cannot for example pose a question. As a result, a great amount of information is lost as the observer obtains many data while reading from the whole face (and torso).

Even though the online test was designed based on previous studies and proposed guidelines we were not able to recruit a satisfactory number of deaf participants to increase the validity of the test. Furthermore, in order to reach more participants the test was distributed online and as a result the homogeny of the group could not be ensured. Another limitation of the test design was that sound was not tested. The absence of sound can decrease the performance of the deaf participants; studies have shown that an audiovisual stimulus obtains greater amount of success in speech perception than audio or visual stimuli alone. Moreover, the videos of *Pugh* speaking were captured from the front angle thus the participants could not change the perspective (e.g. side view or ¾ angle) to gain a better view of the lip movements. All the participants commented that *Pugh* should have more 'human like' characteristics. They found it slightly misleading that the character had an expressionless face and that his eyes, eyebrows and hands did not move properly. They would also prefer if *Pugh* could provide some information using finger-spelling; this feature is discussed below in our future work section. From the lessons learned through this preliminary evaluation we have acknowledged the test procedure's limitations and what it needs to be done to improve it to evaluate the next versions of this application.

5. CONCLUSIONS AND FUTURE WORK

The technological limitations and the character's non-human facial characteristics provide some interesting challenges for the future development of this application. The results have reinforced a need for further development of the lip movement and the facial expressions. *Pugh* has the potential of becoming an educational, entertaining and engaging application for deaf children but in order to achieve this, the contribution and participation of specialist speech therapists in deafness, audiologists, clinical psychologists, teachers of oral communication for deaf or hard of hearing, throughout the development stages is very essential for the success of this application. We have also approached the producers of a children's network channel (CITV) to discuss the potential employment of *Pugh*, once accurate, as a signing character for children's programmes on the network.

This investigation and secondary research on phonetics highlighted the multidimensionality and complexity of speech perception, and the importance of not only accurate lip/teeth/tongue movements but also facial expressions, torso movements and hand/fingers gestures. It is evident that the cartoon character's design has to be reviewed and altered to accommodate these features and animations. As technology continuously evolves, *Pugh's* accuracy in lip movement could be improved by creating a more detailed skeleton rig to achieve an emulation of a human mouth's motions. The tongue, for example, could be mapped more accurately to enhance lip speaking. Part of our future work plan is the addition of cued speech. Cued speech will create a more believable character that has gesticulations that coincide with lip speaking. Deaf children combine strings of gestures to convey ideas, or propositions, similar to the way in which speakers combine strings of words to make statements. Speakers tend to produce only a single iconic gesture for each major idea they say (Mayberry & Nicholadis, 2000). Another valuable component is the potential to present multiple sources of information, such as text, sound and images in parallel (Chun & Plass, 1996). The intent is to maintain the cartoony look of the character and introduce hand gestures, expressions and accurate lip speaking.

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Web-based home rehabilitation gaming system for balance training

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ABSTRACT

Currently, most systems for virtual rehabilitation and motor training require quite complex and expensive hardware and can be used only in clinical settings. Now, a low-cost rehabilitation game training system has been developed for patients with movement disorders; it is suitable for home use under the distant supervision of a therapist. It consists of a patient-side application installed on a home computer and the virtual rehabilitation Game Server in the Internet. System can work with different input gaming devices connected through USB or Bluetooth, such as a Nintendo Wii balance board, a Nintendo Wii remote, a MS Kinect sensor, and custom-made rehabilitation gaming devices based on a joystick. The same games can be used with all training devices. Assessment of the Home Rehabilitation Gaming System for balance training was performed on six patients with Cerebral Palsy, who went through daily training sessions for two weeks. Preliminary results showed balance improvement in patients with Cerebral Palsy after they had completed home training courses. Further studies are needed to establish medical requirements and evidence.

1. INTRODUCTION

Recent experimental evidence suggests that virtual reality technologies have great potential in the neurological rehabilitation of patients suffering from movement and balance disorders (Adamovic *et al*, 2009). Recovery of motor skills depends on neuroplasticity that is driven by repetition, intensity, motivation, and task-oriented training. Currently, there are many different systems designed for virtual rehabilitation and motor training, but most hardware is quite complex and expensive and can be used only in clinical settings. Low-cost, commercially available gaming systems such as Nintendo Wii and Xbox Kinect are widely used at home and have a high potential for movement training (Deutsch *et al*, 2008). However, such typical games are too difficult for neurological patients, whereas therapists have no means to carry out distant supervision of home training sessions. For more than twelve years, specially developed rehabilitation games with gaming devices have been used at our International Clinic of Rehabilitation in order to stimulate motor training in patients with Cerebral Palsy (CP) (Kachmar *et al*, 2001). Now, gaming rehabilitation has become one of the components of the multimodal rehabilitation system and is used on a regular, daily basis (Kozyavkin *et al*, 2004). However, movement training should be continued in home settings after the patient has been discharged from the clinic.

The objective of our work was to develop a low-cost rehabilitation game training system for patients suffering from movement disorders, which would be suitable for home use and under the distant supervision of a therapist. The second aim was to make a preliminary assessment of its benefits for training balance in patients with Cerebral Palsy.

2. DESCRIPTION OF THE TRAINING SYSTEM

The Home Rehabilitation Gaming System was developed to provide game training at home under the supervision of a therapist. It consists of two main parts: a) a patient-side application installed on a home computer – the Game Device Controller (GDC), and b) a virtual rehabilitation Game Server in the Internet. The GDC main functions are to connect gaming hardware, convert data from different hardware to one format, send the game controlling data to the games, and receive feedback.

In our system, GDC can work with different input gaming devices connected through USB or Bluetooth: a Nintendo Wii balance board, a Nintendo Wii remote, a MS Kinect sensor, custom-made rehabilitation gaming devices based on a joystick, and several other. Such an approach allows us to use the same games with all training devices and not develop separate games for each device. Of course, there are some restrictions for game scenarios, and games for disabled persons should not be too complicated.

The virtual rehabilitation Game Server performs the following tasks:

- *User management* – there are different types of users: the patient, therapist, game developer, and systems administrator, all of whom have different interfaces and access rights to the system.
- *Repository for rehabilitation games with training guidelines* – there are instruction for each game, including required gaming devices, training positions, and a short game legend.
- *Usage statistics* – stores and presents graphs on data about game scores, the duration and time of each training session.
- *Messaging* – message support exchange between patients and therapists.

The general structure of the system is presented in Fig. 1.

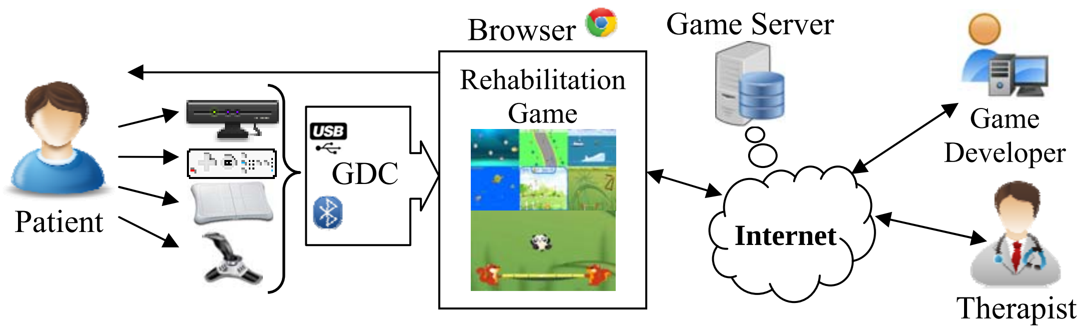


Figure 1. *Scheme of the Web-based virtual rehabilitation system.*

3. REHABILITATION GAMES

Rehabilitation games constitute the most important component of the home training system. They should be rather simple, appropriate for the person with movement disorders and, at the same time, entertaining and fun enough so that the training process does not become boring. Widespread tools, such as the Adobe Flash platform and AS3 language have been selected for game development. A special game user interface was implemented to simplify adding new games to the system and testing them with different training devices. Since the system is multilingual, the game messages are not included directly into the games, but are obtained from the server, depending on the language selected during registration.

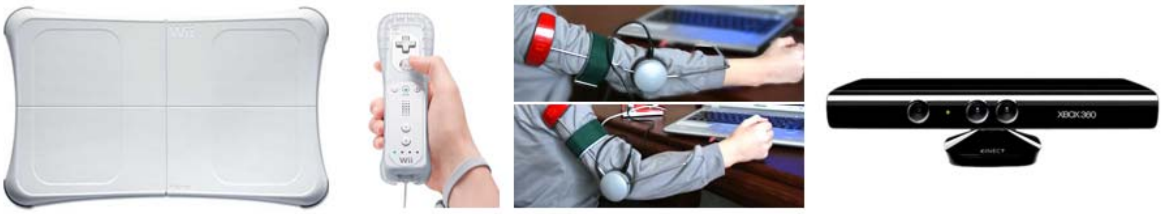
Typically, patients with motor disorders have a limited range of motion. Therefore, before the training session starts, each game is calibrated according to the patient's individual possibilities. He/she needs to perform one or two movements within maximal range and later, games will require the patient to carry out movements that are appropriate for his/her abilities. The games were developed according to a systems standard so that the results of different training sessions could be evaluated. Each game has five levels of difficulty. The first level is quite simple so that even patients with significant movement disorders are able to complete it. Each subsequent level requires more accurate and faster responses. The complexity of the last level is appropriate for a healthy child aged seven to eight years.

A unified scoring system is used in the games. A completed first level earns the patient ten points, the second – fifteen, the third, fourth and fifth – twenty-five points each. The maximal game score comes to 100 points. The score, time, and duration of each gaming session are stored in the database. Currently, there are six games in the system and our team continues working on new ones. Several game screenshots are presented in Fig.2.

4. REHABILITATION GAMING HARDWARE

The following types of rehabilitation gaming hardware are used in the home training system: a) Nintendo Wii balance board, b) Nintendo Wii remote, c) Universal Gaming Device, d) Microsoft Kinect motion sensor.

Figure 2. *Screenshots of rehabilitation games.*



(a) (b) (c) (d)

Figure 3. *Rehabilitation gaming hardware used in the system: a) Nintendo WII balance board b) Nintendo WII remote, c) Universal Gaming Device, d) Microsoft Kinect.*

The Nintendo Wii balance board has four pressure sensors located in each corner of the board; information about center of pressure displacement is transmitted to the computer over the wireless Bluetooth connection. Balance training exercises are performed in different positions – standing, sitting, kneeling, etc.

The Nintendo Wii remote has two accelerometers, making it possible to define its inclination in the gravity field. The Wii remote, attached to a patient's body part, transmits information about its position. For example, if the remote is attached to the patient's chest, the games can be played by bending the body sideways.

The Universal Gaming Device is a custom-made simple electrogoniometer developed at the International Clinic of Rehabilitation. It can be used for tracking movements of elbow, wrist, knee, and ankle joints. Two levers of the device, attached above and below the joint, track flexion/extension movements and are used to control the game.

The Microsoft Kinect motion sensor tracks all body movements. However, in our training system, we choose to track only one or two body parts that are aimed for training. These body parts and required movements are defined in exercise setups and are used for game controlling.

5. HOME TRAINING

Before starting home training sessions, the physical therapist evaluates the patient and draws up a relevant training program, indicating recommended games, training positions, and the frequency and duration of sessions. He registers the patient in the system and trains the child and his parents how to use the system.

The patient or his/her parents should ensure that they have all the required hardware at home; they should download and install Game Device Controller software on the computer, and check the connection of gaming hardware to computer. After setting up the home computer, the patient logs in to the system on the Web-page, selects the recommended games and starts his/her training session.

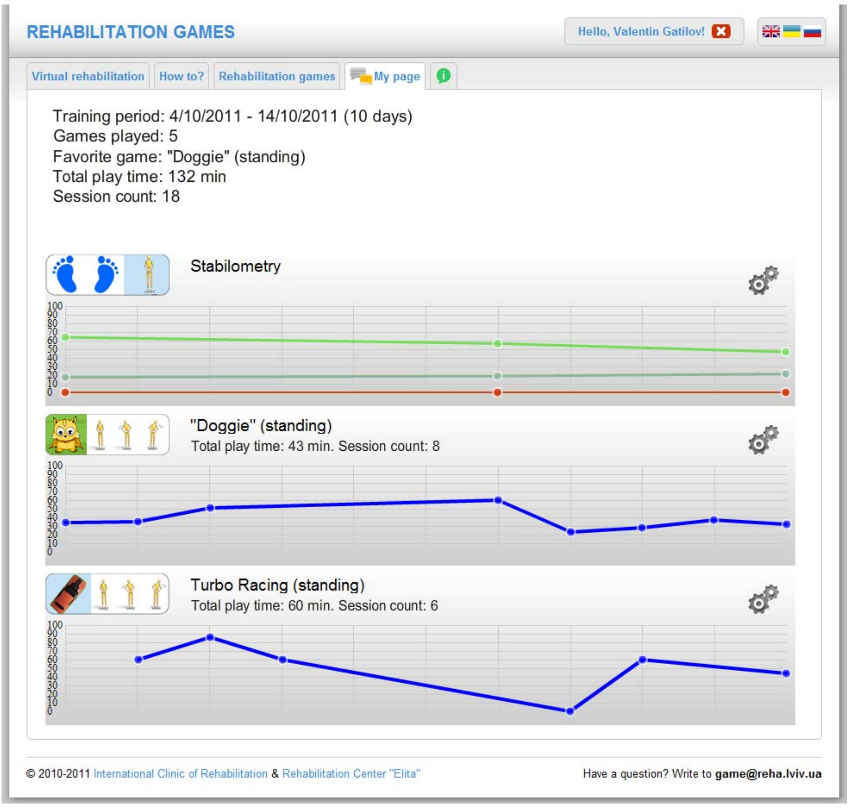


Figure 4. *Results and duration of the training sessions are presented as charts.*

Information about the duration and time of the gaming sessions, as well as game scores are stored in the system and can be viewed in the form of graphs. This information is accessible to the therapist so that the program may be adjusted, if necessary.

6. BALANCE TRAINING EXERCISES

The Game Training System can be used as a supplementary treatment option for patients with different motor problems. This article describes its usage for patients with balance problems. The system is available at http://game.reha.lviv.ua/ and its usage is free for patients and therapists.

A personal computer with an Internet connection and a Bluetooth adapter, a Nintendo Wii balancing board, and a Nintendo Wii remote are required to conduct home balance training exercises. Balance training exercises are aimed at developing coordinated left-right and forward-backward weight-shifting skills and maintaining position. The patient stands or sits on the balance board; while performing specific exercises; at the same time, he/she controls the movements of computer game characters.

Figure 5. *Gaming sessions for balance training.*

Balance training is performed in the following positions: a) standing on the board and shifting body weight left-right, b) standing and shifting body weight forward-backward, standing with support, d) sitting on the board, e) standing with one foot in front of the other, e) kneeling.

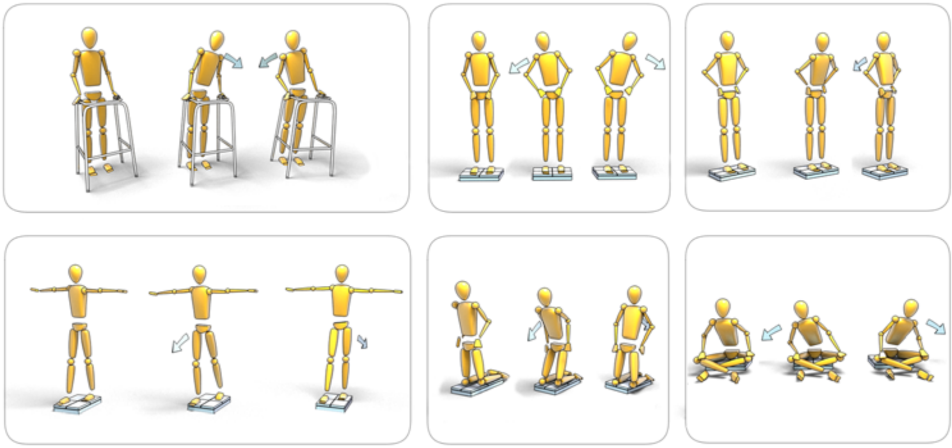


Figure 6. *Training positions for balance exercises.*

7. STABILOMETRY AS A DIAGNOSTIC TOOL MEASURING EQUILIBRIUM

Patients with balance disorders can use our system, which includes a specials diagnostic tool – a game called "Stabilometry", aimed at evaluating balance disorders. The child should stand still on the balance board for fifteen seconds. Two parameters are calculated: the mean velocity of center of pressure (CoP) displacement and area of CoP displacement.

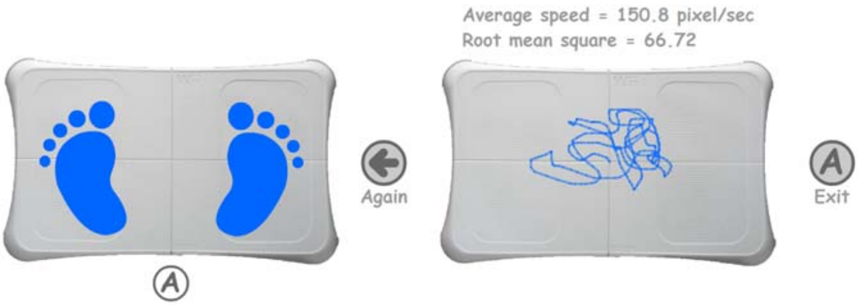


Figure 7. *The Stabilometry game is a tool for testing equilibrium.*

The mean velocity of CoP displacements indicates how briskly the patients sway movements are, whereas the area of CoP shows the range of these movements. Higher velocities and larger areas indicate poor balance. The Stabilometry game has not been validated or certified as a clinical diagnostic tool; it is just an additional tool for patients and parents.

8. PRELIMINARY SYSTEM ASSESSMENT

Preliminary assessment of the Home Rehabilitation Gaming System for balance training was performed on six patients with Cerebral Palsy, who went through daily training sessions for two weeks.

Patients with spastic forms of Cerebral Palsy, aged five to eleven years, cooperative with normal mental development, were selected for the study. All parents and patients were informed and gave their consent for participation. The therapist evaluated each child and drew up relevant training program, indicating recommended games, training positions, and timing. The first two treatment sessions were performed at the rehabilitation center together with the therapist. He registered the patient in the system and trained the child and his parents how to use the system and carry out gaming exercises at home.

For a period of two weeks (twelve sessions), patients conducted daily home training sessions, each lasting thirty minutes. The patients then returned to the rehabilitation center for the second evaluation. The patients were assessed according to standard evaluation systems, whereas their motor development was classified according to the Gross Motor Function Classification System (GMFCS), the Pediatric Balance Scale, and Stabilometry testing.

The Gross Motor Function Classification System (GMFCS) is a five level classification system that describes the gross motor function of children with Cerebral Palsy. Children at Level I can generally walk

without restrictions, but tend to be limited in some of the more advanced motor skills. Children at Level V are generally very limited in their ability to move around even with the use of assistive technology (Palisano *et al*, 1997).

The Pediatric Balance Scale (PBS) is an instrument with proven reliability and validity, designed to evaluate the child's balance function, including his/her ability to move around in the surrounding environment (Franjoine *et al*, 2003). It is a modification of Berg's Balance Scale, developed as a balance measure for school-age children with mild to moderate motor impairments. The scale consists of fourteen tasks; each has a scoring scale from 0 to 4 points; the maximum score is 56. The distribution of patients according to age, gender, diagnosis, and GMFCS level is presented in Table 1. The majority of patients were in the five-to-eight-year-old group, predominantly with hemiplegic Cerebral Palsy. Four of them were classified at Level I of motor development; one walked with limitation (Level II), and one girl with spastic tetraplegia was able to walk only with assistance (Level III).

Table 1. *Distribution of patients according to diagnosis, age and GMFCS level.*

Patient	Age (years)	Gender (M/F)	Diagnosis	GMFCS level
A	5	M	CP, spastic right-sided hemiplegia	I
B	5	F	CP, spastic right-sided hemiplegia	II
C	7	F	CP, spastic right diplegia	I
D	7	M	CP, spastic right-sided hemiplegia	I
E	11	M	CP, spastic left-sided hemiplegia	I
F	8	F	CP, spastic tetraplegia	III

9. RESULTS AND DISCUSSION

Assessment results of six patients before and after a two-week home gaming training course are presented in Table 2. The same information is presented as charts in Fig. 8.

Table 2. *Balance testing results of six patients with Cerebral Palsy before and after home game training.*

Patient, age	GMFCS level diagnosis,	Before training			After training		
		Balance Scale	CoP Velocity	CoP Area	Balance Scale	CoP Velocity	CoP Area
A, 5 years	Level I, hemiplegia	52	25	8	53	23	8
B, 5 years	Level II, hemiplegia	45	50	8	46	46	7
C, 7 years	Level I, diplegia	47	29	14	48	25	9
D, 7 years	Level I, hemiplegia	48	22	3	50	26	4
E, 11 years	Level I, hemiplegia	49	31	8	51	24	7
F, 8 years	Level III, tetraplegia	7	48 (with support)	7 (with support)	7	44 (with support)	5 (with support)

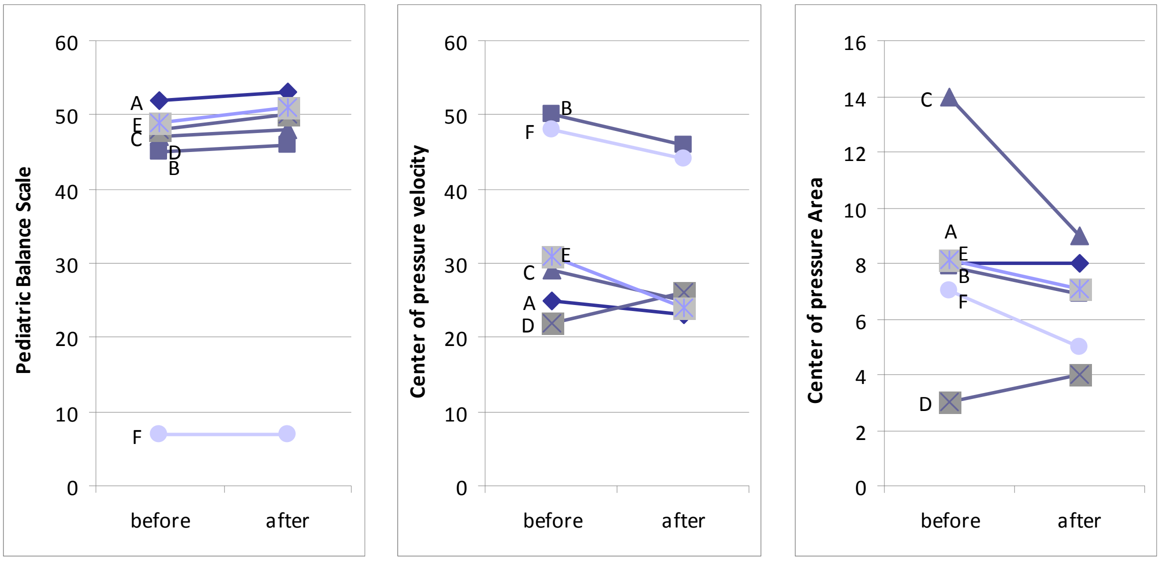


Figure 8. *Graphical representation of balance testing data of six patients with Cerebral Palsy before and after game training courses.*

10. CONCLUSIONS

A Home Rehabilitation Gaming System was developed in order to transfer the virtual rehabilitation of patients with motor disorders from clinical to home settings.

Studies indicate the feasibility of this Home Rehabilitation Gaming System to train the patients' balance function. Preliminary results show balance improvement in patients with Cerebral Palsy after home training courses. Further studies are needed to establish medical requirements and evidence.

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The Home Rehabilitation Gaming System is available free-of-charge to both therapists and patients at: (http://game.reha.lviv.ua).

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Balance rehabilitation using custom-made Wii Balance Board exercises: clinical effectiveness and maintenance of gains in acquired brain injury population

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ABSTRACT

Balance disorders are a common impairment of some of the pathologies with the highest incidence and prevalence rates. Conventional physical therapy treatment focuses on the rehabilitation of balance skills in order to enhance patients' self-dependency. In the last years, some studies have reported the clinical benefits of virtual reality systems in the balance recovery. The force platform Wii Balance Board has been adopted with rehabilitative purposes by many services due to its low cost and widespread battery of exercises. However, this entertainment system is oriented to healthy people and cannot adapt to the patient's motor (and possible cognitive) deficits. In previous studies we have developed custom-made adaptive exercises that use the Wii Balance Board with promising results in acquired brain injury population. In this contribution, we present some conclusions derived from the past and undergoing clinical studies.

1. INTRODUCTION

There are multiple pathologies, such as acquired brain injury (ABI), multiple sclerosis, Parkinson and Alzheimer disease, or vestibular disorders that can induce balance complications (Cheng et al, 2012), which can directly or indirectly affect the performance of the activities of daily living (Tyson et al, 2007). The rehabilitation strategies consider specialized programs to regain balance in order to enhance the patients' self-dependency. The improvement of the balance control has been traditionally assessed by functional scales and posturography studies, which aim to objectively quantify the balance condition through measurements of the center of pressure (COP). The COP has proven to be a relevant indicator of the patients' balance condition (Ruhe et al, 2011; Terry et al, 2011). Since the COP can be directly estimated from the individuals' weight distribution on a force platform, several systems based on force plates have come onto the market in the last years. Although their initial purpose was to provide therapists with new assessment tools, some of these systems also provide rehabilitation exercises.

The Nintendo® Wii Balance Board (WBB), a peripheral of the Nintendo® Wii gaming system which was launched with entertainment purposes, has achieved a great acceptance in the clinical community, since their performance can be compared to professional systems with significant lower cost (Clark et al, 2010). In addition, the WBB is portable, works wirelessly, and its setup is not time consuming. There are an increasing number of studies involving the WBB. Most of them use off-the-shelf games with balance rehabilitation purposes (Sugarman et al, 2009). However, even though these games can be motivating, they are oriented to the entertainment of healthy population and can require motor and cognitive skills that disabled individuals can lack. The studies involving custom made rehabilitative exercises are especially interesting (Gil-Gomez et al, 2011), since they are specifically designed with rehabilitative purposes, can provide patients with contents

adapted to their particular motor and cognitive impairments, and can provide therapists with objective data of the evolution of the patients.

In previous studies we have designed and studied the clinical effectiveness of the eBaViR (easy balance virtual rehabilitation) system, a set of custom made WBB exercises for chronic ABI patients with promising results (Gil-Gomez et al, 2011). The objective of this paper is to present our experiences and conclusions in the design and in the validation of adapted balance rehabilitation exercises involving the WBB.

2. METHODS

All the clinical data presented here are extracted from two studies that involve chronic ABI patients of the neurorehabilitaion service of Hospital NISA Valencia al Mar. The first study was carried out in 2010 and the second one is being currently carried out. Both studies have the same inclusion/exclusion criteria. The inclusion criteria were: 1) age ≥16 years and <80 years; 2) chronicity > 6 months; 3) absence of cognitive impairment (Mini-Mental State Examination (Folstein et al, 1975) cut-off >23); 4) able to follow instructions; 5) ability to walk 10 meters indoors with or without technical orthopaedic aids. The exclusion criteria were: 1) patients with severe dementia or aphasia; 2) patients whose visual or hearing impairment does not allow possibility of interaction with the system; 3) patients with hemispatial neglect; 4) patients with ataxia or any other cerebellar symptom.

The objective of the first trial was to study if custom made rehabilitative exercises on a force platform could improve the balance condition of ABI patients when comparing to conventional physical therapy programs. To prove this hypothesis a randomized controlled trial was carried out. The objective of the ongoing second trial is to study if improved versions of the exercises have similar effects and if they persist in absence of the virtual training. In this case, a follow-up study was designed.

2.1 First Study

The study evaluated the clinical effectiveness of the first prototype of the system. The first version of the eBaViR system included 3 exercises to train discrete displacements of the COP in the medial-lateral plane (air hockey), and in the medial-lateral and anterior-posterior planes (Simon), and free displacements (balloon breaker) (Figure 1).

Figure 1. *Patients interacting with the first prototype of the system*

After inclusion/exclusion criteria, the final sample consisted of 20 patients, which were categorized depending on their falling risk and randomized to a control or an experimental group afterwards (Table 1). 3 participants dropped out of the treatment.

All the participants underwent 20 one-hour sessions, from 3 to 5 sessions per week. The control group underwent traditional physical therapy and the experimental group used the developed system. The balance condition of all the participants was assessed by the Berg Balance Scale (BBS) (Berg et al, 1992), the Brunel Balance Assessment (BBA) (Tyson and De Souza, 2004), the Anterior Reach Test (ART) (Duncan et al,

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1990), and by other more dynamic scales such as the Timed Stair Test (TST) (Perron et al, 2003), the Stepping Test (ST) (Fujisawa et Takeda, 2006), the 1-minute Walking Test (1MWT) (McDowell et al, 2005), the 10-meter Walking Test (10MT) (Steffen et al, 2002), the Time "Up and Go" Test (TUG) (Steffen et al, 2002) and the 30-second Sit-to Stand Test (30SST) (Verschuren et al, 2002).

Table 1. *Characteristics of the participants of the first study.*

Issue	Control group	Experimental group	Significance
Gender (n)			NS (p=0.858)
Male	5 (29.4%)	6(35.3%)	
Female	3(17.7%)	3(17.7%)	
Age (years)	49.13±21.18	45.78±15.38	NS (p=0.704)
Etiology (n)			NS (p=0.657)
Stroke	5 (29.4%)	6 (35.3%)	
Traumatic brain injury	1 (5.9%)	2 (11.8%)	
Benign cerebral neoplasm	2 (11.8%)	1 (5.9%)	
Time since injury (days)	675.50±283.11	478.00±324.77	NS (p=0.204)

Age and time since injury are defined in terms of mean and standard deviation. Etiology and gender are also expressed as a percentage of the total number of patients. NS: non-significant.

2.2 Second Study

The second study is currently being carried out to study the clinical effectiveness of the second version of the system and the maintenance of gains. The second version of the system includes 4 exercises that require discrete displacements of the COP and 2 exercises that require free displacements, with versions for standing and sitting position. In addition, the system includes exercises for training one-leg standing, stair climbing, one-foot rising and sit-to-stand transfer (Figure 2).

Figure 2. *Patients interacting with the second prototype of the system*

Till date, 7 participants, from an expected final sample of 21 chronic ABI patients have finished the training with the virtual system (Table 2).

The participants also underwent 20 one-hour sessions, 3 to 5 times per week. Each participant trained with the prescribed exercises that mostly fit their needs according to the therapists. A similar battery of balance scales and tests was administered to each participant at the beginning, at the end, and one month after the trial (follow-up assessment). Similarly to the first study, each participant's condition was assessed with the BBS, the ART, the ST, the TUG, and the 30SST.

Table 2. *Characteristics of the participants of the second study.*

Issue	Experimental group
Gender (n)	
Male	6(85.7%)
Female	1(14.3%)
Age (years)	48.08±16.03
Etiology (n)	
Stroke	7 (100.0%)
Traumatic brain injury	0
Benign cerebral neoplasm	0
Time since injury (days)	439.86±103.99

Age and time since injury are defined in terms of mean and standard deviation. Etiology and gender are also expressed as a percentage of the total number of patients.

3. RESULTS

3.1 First Study

No significant differences in demographical (age and gender) or clinical (chronicity, etiology, and laterality) variables at inclusion were detected between groups (Table 1).

A repeated measures ANOVA revealed a significant time effect for the BBS, BBA, standing ART, ST-paretic, ST-non paretic, 1MWT, TUG and 30SST (Table 3). No group effect was detected for any outcome, which confirms the comparability of both groups. Finally, significant group-by-time interaction was detected in the scores of the BBS and the ART in standing position.

Table 3. *Clinical data of the first study.*

Scale	Group	Before treatment	After treatment	Significance
BBS	Control Trial	45.38±7.35 41.22±10.57	46.88±6.15 45.44±8.62	T**(p=0.000) GxT*(p=0.011)
BBA	Control Trial	11.00±.1.31 10.00±2.00	11.13±1.13 10.33±2.18	T*(p=0.048)
ART standing (cm)	Control Trial	25.44±9.33 24.13±7.70	25.63±9.74 27.25±10.38	T**(p=0.005) GxT*(p=0.011)
ART sitting (cm)	Control Trial	40.06±6.87 34.83±11.92	40.13±7.66 37.78±12.34	NS
ST paretic (n)	Control Trial	6.57±2.30 6.75+3.58	7.57±2.44 7.63±4.00	T*(p=0.021)
ST non-paretic (n)	Control Trial	8.17±1.72 9.33±2.81	9.50±3.39 10.50±3.02	T*(p=0.046)
TST (s)	Control Trial	14.82±9.42 15.38±9.69	12.13±4.94 13.52±9.60	NS
1MWT (m)	Control Trial	31.13±13.59 31.94±12.47	36.38±15.39 42.69±20.43	T**(p=0.007)
10MT (s)	Control Trial	14.57±10.95 13.47±8.29	14.07±9.02 13.47±10.64	NS
TUG (s)	Control Trial	24.00±14.87 20.99±15.11	19.52±10.91 18.69±13.43	T**(p=0.004)
30SST (n)	Control Trial	6.88±3.52 7.56±4.19	8.50±3.12 9.00±4.74	T**(p=0.003)

The results are given in terms of mean and standard deviation. G: group effect. T: time effect. GxT: group/time effect. * $p<0.05$, ** $p<0.01$. n represents the number of repetitions.

3.2 Second Study

A repeated measures ANOVA revealed significant time effect between the initial and the final assessment in all the measures. In addition, significant time effect was detected between the final and the follow-up assessment in the BBS, and the 30SST.

Table 4. *Clinical data of the second study.*

Scale	Initial assessment	Final assessment	Follow-up assessment	Significance
BBS	37.00±7.30	42.00±6.73	43.86±6.73	T_1**(p=0.002) T_2**(p=0.011)
ART standing(cm)	23.57±3.99	28.64±8.12	29.86±8.15	T_1*(p=0.049)
ST paretic (n)	2.86±2.19	5.14±1.95	5.71±2.43	T_1**(p=0.012)
ST non-paretic (n)	5.14±2.79	7.14±3.08	8.43±3.31	T_1**(p=0.022) T_2**(p=0.001)
TUG (s)	32.71±17.20	28.05±16.08	22.92±12.13	T_1*(p=0.045) T_2*(p=0.021)
30SST (n)	6.29±2.93	10.14±4.67	11.14±4.98	T_1**(p=0.012) T_2**(p=0.018)

The results are given in terms of mean and standard deviation. T_1: time effect between the initial and the final assessment. T_2: time effect between the final and the follow-up assessment.
* p<0.05, ** p<0.01. n represents the number of repetitions.

4. DISCUSSION

The statistical analyses showed that the balance training through low-cost force platforms and custom made exercises can provide clinical benefits to ABI chronic patients. Similar results were achieved in both studies (Table 5), which confirms the effectiveness of both designs.

Table 5. *Comparison of the results of both studies between the initial and the final assessment.*

Scale	First design	Second design
BBS	T**(p=0.000)	T**(p=0.002)
ART standing	T**(p=0.005)	T*(p=0.049)
ST paretic	T*(p=0.021)	T**(p=0.012)
ST non-paretic	T*(p=0.046)	T**(p=0.022)
TUG	T**(p=0.004)	T*(p=0.045)
30SST	T**(p=0.003)	T**(p=0.012)

T: time effect. GxT: group/time effect. * p<0.05, ** p<0.01.

As shown in the first study, custom made exercises on force platforms show significant improvement in the BBS and in the ART in standing position when compared to traditional physical therapy (Table 3). This can be due to the specificity of the exercises, since they require repetitive displacements of the COP and the consequent adaptation of postural responses. The training of these tasks can lead to an improvement that can be reflected in those scales. No significant group effect or group-by-time interaction was either detected for any of the dynamic scales, which suggests that both groups improved in the same way and that the system mainly promotes the recovery of static balance, in which the system focuses on its exercises, while it has no significant effect in dynamic balance. No specific exercises for the dynamic skills of balance were included and consequently the training does not provide special benefits to conventional physical training. However, several outcomes showed significant time effect of the training in scales that focused on balance skills during gait, such as 1MWT and TUG, or other complex motor tasks, such as 30SST and ST.

According to the results of the second trial, the results show that the improvement between the initial and the final assessment lasts along time. Moreover, the participants show significant improvement in the follow-up assessment in the scales of BBS, ST (in the non-paretic side), TUG, and 30SST. The training with the virtual system could have provided an improvement in the balance condition that supported the progressive improvement of these skills after the treatment, even in dynamic activities, as shown in the TUG.

These results must be taken into account considering the limitations of the studies and the sample. However, the improvement of the patients that underwent the virtual therapy in both studies is remarkable due to the chronicity of the sample (478.00±324.77 and 439.86±103.99, respectively), which is higher that than the 6-month period which is traditionally considered as the period with maximum recovery (where spontaneous recovery takes place) (Jorgensen et al, 1995).

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Upper-body interactive rehabilitation system for children with cerebral palsy: the effect of control/display ratios

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ABSTRACT

We have developed a virtual reality rehabilitation system using upper-body interaction with Microsoft KinectTM. With the use of KinectTM , the system enables a patient a full-range of avatar movements to adapt the Control/Display (C/D) ratio of a limb's position in 3D space. In this paper, we have explored the effectiveness of C/D ratios in our prototype application to analyze user performance, work load, and user enjoyment with university students without motor impairments. Our findings suggest that the C/D ratio is related to task difficulty, movement strategy, and user motivation.

1. INTRODUCTION

Cerebral palsy (CP) is a term that refers to various motor impairments caused by damage to the central nervous system during foetal development (Krageloh-Mann and Cans, 2009). This disorder affects approximately 0.3% of births (Krageloh-Mann and Cans, 2009) and often manifests itself during childhood as a difficulty to use one side of the body (hemiparesis). Motor deficits encompass difficulty in planning and executing movement. Children with impaired motor function need physical therapy in order to improve their movement patterns and to maintain the range of the affected arm and leg joints. Constraint-induced movement therapy (CIMT) if often used to improve upper limb function (Hoare et al., 2007). CIMT encourages the use of the affected hand by restricting the unaffected hand and asking for intensive movement with the impaired upper limb. To be efficient, this approach demands intensity. Having the "good" arm blocked for long periods of time can generate frustration in the child and might not be applicable in a long-term rehabilitation program. More "child-friendly" approaches are needed during the neuro-development of children with CP. For example, rehabilitation programs could offer therapeutic games that are specifically designed to encourage the child to use their affected limb.

The field of Virtual Reality (VR) has grown dramatically as an emerging tool that has great potential for use in rehabilitation (Le Gal et al., 2008). VR systems offer the capability to achieve rehabilitative goals through the use of real-time feedback and adaptive strategy/difficulty (Rose et al., 2000). Traditional CP therapy involves repetitive movement as a key means of motor rehabilitation. However, such traditional therapies are often of little interest to a child, affecting his motivation to continue such therapeutic activities (Schmidt and Lee, 2005). VR offers boundless variations of augmented feedback, objects, orientations, and creative environments. Likewise, all parameters of a Virtual Environment can be varied under repeatable conditions (Cikajlo and Matjacic, 2009) so that the VR remains motivating and entertaining (Rand, 2007).

The objective of this project was to develop a game, adapted to children with CP, that would encourage the child to use their affected hand and, thereby, to improve their movement and motor control of the limb. A rather simple task was chosen: to catch objects, traveling in various directions, with one hand using a Microsoft KinectTM sensor. A specialized algorithm was developed to aid the Kinect sensor in recognizing the paralyzed arm's limited field of movement. Additionally, an application was developed to penalize the use of the unaffected arm to encourage the child to use the affected arm.

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2. RELATED STUDIES

Virtual rehabilitation is conducted through the use of virtual reality (VR) and virtual environments (VE) within rehabilitation. VR and VE can be described as a multi-sensory, interactive, computer-based environment, that simulates a real world environment. Virtual rehabilitation has potential therapeutic benefits due to the immersive graphical nature and the realistic interaction techniques; it has attracted considerable attention in research and clinician communities (Halton, 2009). Besides its immersive nature, VR is able to provide motivation whereby individuals tend to have fun and are more motivated to continue rehabilitation (Berger-Vachon, 2006). In addition, the advantages associated with the use of Virtual Rehabilitation are that the same VR hardware can be used for various types of patients, as well as for various types of exercises (Burdea, 2003).
There are a few Virtual Rehabilitation systems for motor-learning rehabilitation using full-body interaction. IREX (Kizony et al., 2003) is a projected video-capture system. A single camera is used for vision-based tracking to capture the user's movements. The captured video images can be displayed on a connected TV screen, corresponding in real time to his movements. Its suitability has been investigated for use during motor or cognitive rehabilitation (Kizony et al., 2002). The EyeToy game also uses a single camera to capture the user's movements. Interaction with an on-screen user avatar can only track movements in a single plane and is not able to record body movements (Fitzgerald et al., 2007). The Cybex Trazer® employs a single infrared beacon which is mounted on a belt worn around the waist of the user. The user's motion is captured by monitoring the sensor's position by the tracker bar (Fitzgerald et al., 2007).

In the previously-mentioned studies, the investigated systems have limited working space visually since the user's movement is directly projected on a screen via a tracking system, even though a patient with impaired motor function has a limited range of movement. If the programmed training is successfully conducted, a patient might feel confident since he feels his movement range gradually improving. However, in most cases the training takes place over a long time and we believe that these patients have difficulty keeping their motivation high until they see their improved movement. Furthermore, users' limited working space may limit system capability such as task variation and interaction techniques for the rehabilitation task.

The goal of the project was to develop a full-body, interaction, virtual-rehabilitation system using Microsoft Kinect, which enables children with hemiparesis to improve their affected hand. Our purpose is to assist them in a full-range of avatar movements to adapt the Control/Display ratio of limb/joint positions in 3D space from the Kinect. In this paper, we begin to explore the effectiveness of C/D ratios in our prototype application to analyze user performance, work load, and user enjoyment with university students without motor impairments.

3. PROPOSED SYSTEM

3.1 Hardware configuration

Figure1 illustrates the proposed system configuration, composed of one 60" TV monitor, one laptop, one Microsoft Kinect sensor, and one rehabilitation application running on the laptop. The application renders a visually-realistic 3D environment.

Figure 1. *Illustration of the system environment.*

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3.2 Virtual rehabilitation application

The rehabilitation application was developed to support rehabilitation for children with impaired motor functions. The application supports the rehabilitation of arm movements through natural, full-body interaction.

Figure 2 shows a screen shot of the main interface of the rehabilitation application. In the application, an avatar is displayed in the center of the TV monitor. The avatar represents a user's full body movement. The user controls the virtual avatar and attempts to touch a virtual object that moves around within the virtual space. The application can change the properties of the virtual object such as direction, velocity, size, shape, and so on.

The application uses the Kinect sensor to obtain 3D positional data for the user's left/right hands, wrists, elbows, and shoulders. However, the user's avatar hand movements are represented alongside the circle which is displayed in the center of the screen. That is, the positional data is converted to 2D positional data and rendered in real time via the user's avatar hence providing visual feedback to support the reduction of motor error.

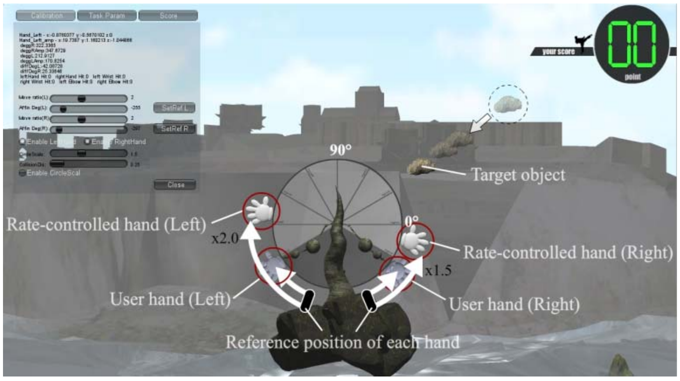

Figure 2. *Screenshot of rehabilitation application – C/D ratio is set up for both hands: 2.0 for the left hand, and 1.5 for the right hand. Both the left/right hand avatar disappear when the task begins. The degree of the object's direction is rotated counter-clockwise.*

In the training mode, the system supports two interaction techniques: One hand (only the left or right hand is used) and both hands (left/right hands are used simultaneously or independently). Each interaction technique trains the subject's arm movements though a virtual-object touching task in which a user is required to touch a target object traveling in various directions within the virtual space using their activated hand (e.g. left hand if the selected interaction technique is left hand interaction).

3.3 Hand movements with a Control/Display (C/D) ratio

The Control/Display (C/D) ratio is a ratio between the amplitude of movement of the user's real hand and the amplitude of movements of the virtual cursor (Dominjon et al., 2005). In most cases using a Virtual Environment, the C/D ratio may be set up based on the user's physical working space where the user is able to move in the virtual work space with a full range of movements.

Since a patient with an impaired motor function has a limited range of movement, the system assists in full-range avatar movements to change the C/D ratio. As shown in Figure 2, two avatars are displayed simultaneously for each hand: The user avatar (UA), and the amplitude user avatar (AUA). The UA's movement corresponds to the user's actual limited movement. The AUA's position is updated based on the C/D ratio. For example, if the C/D ratio is set at 2.0, then the AUA's movements will be double the range of the UA's movements.

3.4 Sample rate of the captured joint position

If the sample rate of joint positions is not frequent enough, the data would not provide enough information about a patient's' movements. The sample rate was simulated in each type of designed training mode. The sample rate data were collected while each mode is playing for 2 minutes. As a result of the simulation, the average sample rate was 20.67 Hz (SD = 2.51). According to the simulated average sample rate, the joint positions were recorded about 20 times per second.

4. SYSTEM EVALUATION

The purpose of this evaluation is to assess the effectiveness of a C/D ratio in terms of user performance, work load, and user enjoyment. In this paper, we assess the prototype system in the one-hand condition (only using the user's dominant hand).

4.1 Participants

Twelve participants (9 male and 3 female), between 19 and 30 years (Mean, M = 24.3, Standard Deviation, SD = 3.3 years) were used from university students. All participants were right-handed, in good health, and had not used a game using Kinect.

4.2 Apparatus

One Kinect was used for training exercises and experimental tasks (see Figure 1). The Unity3D platform was used for graphic rendering. Kinect was updated to about 20Hz. All tasks were performed using a TOSHIBA laptop running on Windows 7 with an Intel Core i7 720QM processor and 4GB of memory. All subjects were at a distance of about 3 meters from the Kinect sensor.

4.3 Task Procedure

In this study, the independent variable is the C/D ratio. Three main tasks were conducted using three different C/D ratios: 1.0 (no amplitude), 1.5, and 2.0. To remove the sequence effect, the three main tasks were completely randomized. Each main task contains a training session, a trial session, and a questionnaire session.

The purpose of the training session is to learn how to play the object catching trial using Kinect. In the training session, the C/D ratio was set at the same value as the trial session. Between 20 and 40 objects were represented randomly from different directions to cancel the training effect. Each object was represented every 2 seconds. The subjects were required to catch the object with their dominant hand.

In the trial session, 60 objects were used. The subjects were required to use their dominant hand to catch the 60 objects. The applied direction of the object was visually different among the three C/D ratio conditions: [-40°,-5°,60°] for C/D 1.0, [-25°, 27.5°, 125°] for C/D 1.5, and [10°, 60°, 190°] for C/D 2.0. Their degree was randomly selected and applied. However, every time an object with an even order number was applied, the subjects were required to put their dominant hand on their side, that is, to its initial position of -70°. Each object was represented every 2 seconds.

After concluding the trial session, the subjects were asked to complete a NASA TLX questionnaire, and a Physical Activity Enjoyment Scale (PACES) questionnaire.

5. RESULTS

Three dependent variables were used for analyzing the subject's performance and the subjective data in the conducted tasks: Task success rate, work load, and enjoyment. A one-way ANOVA analysis was carried out to find the effects of the dependent variables. Table 1 shows the results.

Table 1. *Results of variance analysis*.

Independent Variable	Dependent Variable							
	Task success rate	NASA TLX						Physical Activity Enjoyment Scale
		Mental Demand	Physical Demand	Temporal Demand	Performance	Effort	Frustration	Enjoyment
C-D ratio df(2,32)	F = 6.57**	F = 1.77	F = 1.97	F = 2.67 †	F = 0.84	F = 4.01*	F = 0.03	F = 0.23

† $p < 0.1$, * $p < 0.05$, ** $p < 0.01$

5.1 Task success rate

The task success rate was defined as the user success rate which is the percentage of tasks that users complete correctly.

A significant effect was found, $F(2,32) = 6.57$, $p = 0.004$. Bonferroni follow-up tests revealed that the C/D ratio 1.0 condition (M = 99.72% , SD = 0.96%) was significantly higher than the C/D ratio 2.0 condition (M = 90.28% , SD = 10.77%). Furthermore, the C/D ratio 1.5 condition (M = 97.50% , SD = 3.51%) was significantly higher than the C/D ratio 2.0 condition.

5.2 Workload

The NASA Task Load Index (TLX) was used to measure the workload of the subjects. It contains six subscales: Mental demands, physical demands, temporal demands, performance, effort, and frustration. All items were rated on a 7-point scale. Concerning mental demand, physical demand, temporal demand, effort and frustration, a low value indicates less workload experienced, whereas higher values indicate more workload experienced. Concerning performance, lower values indicate better performance, and higher values represent poorer performance.

Concerning mental demand, physical demand, performance and frustration, there was no significant difference for the different conditions. For temporal demand, ANOVA revealed a significant trend for condition, $F(2,32) = 2.67$, $p < 0.1$, Bonferroni follow-up tests revealed that the C/D ratio 2.0 condition (M = 3.67 , SD = 1.15) was significantly higher than the C/D ratio 1.0 condition (M = 2.67 , SD = 0.98). For effort, ANOVA revealed a significant trend for condition; $F(2,32) = 4.01$, $p = 0.027$, Bonferroni follow-up tests revealed that the C/D ratio 2.0 condition (M = 3.41 , SD = 1.24) was significantly higher than the C/D ratio 1.0 condition (M = 2.08, SD = 0.67).

5.3 Enjoyment

The Physical Activity Enjoyment Scale (PACES) was used to assess enjoyment (Kendzierski and DeCarlo, 1991). PACES is an 18-item questionnaire that measures an athlete's perceptions of enjoyment derived from participation in a physical activity such as sport. Average value of the 18 subscales was used as the Enjoyment.

For Enjoyment, ANOVA revealed that there was no significant difference among different conditions.

6. DISCUSSION

The aim of the study was to explore the capability of the prototype application to assess user performance, work load, and enjoyment for the purpose of rehabilitation.

The results showed that there was a significant effect on task success rate and effort, as well as a significant trend on temporal demand. For the task success rate, performance in the C/D ratio 1.0 condition was significantly higher than that in the C/D ratio 2.0. Furthermore, performance in the C/D ratio 1.5 condition was significantly higher than that in the C/D ratio 2.0. These results indicate that the value of the C/D ratio affects task difficulty. Indeed, during the main task, the applied direction of the object was visually different among the three C/D ratio conditions: [-40°,-5°,60°] for C/D 1.0, [-25°, 27.5°, 125°] for C/D 1.5, and [10°, 60°, 190°] for the C/D 2.0 condition. However, the user's real hand movements are the same among these C/D ratio conditions. During interviews, a couple of subjects made a comment about the effect of the visual gap. That is, with a C/D 2.0 ratio they were required to make more of a cognitive plan for object targeting by controlling their hand movement speed, as well as adjusting hand position. This indicates that even if the real hand movement area is the same among different C/D ratios, the user's behavior was different, that is, the user's movement strategy for the task could change.

These effects were observed on the resulting work load. The temporal demand in the C/D ratio 2.0 condition was significantly higher than that in the C/D ratio 1.0 condition. Furthermore, effort in the C/D ratio 2.0 condition was significantly higher than that in the C/D ratio 1.0 condition. Due to the visual gap, subjects commented that they were required to make an effort to complete a task with a C/D 2.0 ratio as well as feeling time pressure with a C/D 2.0 ratio. Concerning frustration, we expected that users feel stress for avatar operations in C/D 1.5 and 2.0 ratio conditions. However, there was no significant effect depending upon the condition. According to the user's comments, he felt comfortable for the C/D 2.0 ratio condition because of the speed of the avatar's movement. For the C/D 1.0 ratio condition, he felt uncomfortable because the avatar's movement was slow. However, there was also an opposite comment for this point of view.

Concerning enjoyment, there was no significant difference among these C/D ratio conditions. However, according to the users' comments, the user could be challenged, excited, and motivated to perform the task with a C/D 1.5 and 2.0 conditions. Concerning the C/D 1.0 condition, the users commented that the

movement was realistic, natural, and simulated. This result indicates that user motivation can be changed with different C/D ratios. Pasch (2008) indicated that user motivation was related to movement strategies. They employed a Wii Boxing game for their study, hence the result was for a specific game scenario. However, our results take into consideration a more generic point of view since the effect was assessed on a primitive interaction level to change the C/D ratio. This finding could possibly be used for designing adaptive, motivational instruction for any kind of VR rehabilitation system.

7. CONCLUSION

In this study, we explored the effectiveness of C/D ratios in our prototype application to analyze user performance, work load, and user enjoyment with university students without motor impairments. The results show that the C/D ratio was related to task difficulty, movement strategy, and user motivation. Future work on different kinds of C/D ratios will be designed to better understand their effectiveness. In addition, other kinds of interaction techniques we have developed will be investigated using patients with impaired motor function.

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Combining virtual reality and a myo-electric limb orthosis to restore active movement after stroke: a pilot study

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ABSTRACT

We introduce a novel rehabilitation technology for upper limb rehabilitation after stroke that combines a virtual reality training paradigm with a myo-electric robotic limb orthosis. Our rehabilitation system is based on clinical guidelines and is designed to recruit specific motor networks to promote neuronal reorganization. The main hypothesis is that the restoration of active movement facilitates the full engagement of motor control networks during motor training. By using a robotic limb orthosis, we are able to restore active arm movement in severely affected stroke patients. In a pilot study, we have successfully deployed and evaluated our system with 3 chronic stroke patients by means of behavioral data and self-report questionnaires. The results show that our system is able to restore up to 60% of the active movement capacity of patients. Further, we show that we can assess the specific contribution of the biceps/triceps movement of the paretic arm to the virtual reality bilateral training task. Questionnaire data show enjoyment and acceptance of the proposed rehabilitation system and its VR training task.

1. INTRODUCTION

Currently, stroke is one of the main causes of adult disability, and by 2030 it is expected to be one of the main contributors to the burden of disease worldwide (WHO 2008). An important goal in the management of stroke patients, in particular in patients with spasticity, involves restoration of normal limb position and ease of passive and active movement execution with the aim of improving functional outcomes such as the ability to carry out activities of daily living (Esquenazi 2004). This is a very demanding task for trained therapists. This is especially problematic in patients with low level of motor control and yet aggravated in the presence of spasticity. In fact, 85% of stroke survivors will present a motor deficit contralateral to the location of the brain lesion (Lai, Studenski et al. 2002). Additionally, 20–40% will also suffer of increased muscle tone or spasticity, what will further limit their level of independence in the activities of daily living (Watkins, Leathley et al. 2002; Sommerfeld, Eek et al. 2004). The large economical and psychological impacts of stroke on our society, in particular on relatives and public health systems, make it necessary to find alternative and novel approaches to address these issues.

Nowadays, it is well understood that recovery after stroke depends on brain mechanisms that allow undamaged brain areas such as contralateral or secondary networks to take over the functions of the damaged areas (Sabatini, Toni et al. 1994; Seitz, Butefisch et al. 2004; Dobkin 2008). In the chronic stage of stroke, neuronal plasticity is the main contributor to true recovery, being dependent on the size, severity, and location of the lesion (Nudo 2007; Murphy and Corbett 2009). Therefore, modern rehabilitation approaches should aim at providing an effective way of driving cortical plasticity and recruiting alternative motor areas to achieve functional brain reorganization, while being accessible to the widest range of patients, in particular to those with worse prognostic. During the intent to perform a motor action, the cortical areas devoted to motor control generate particular activity patterns – reflecting the synchronization and desynchronization of neural activity – known as Sensory Motor Rhythms (SMR) (see Hatsopoulos (2009) for a review). These activity patterns encode motor control signals that can still reach the paretic arm, as long as there are remaining cortico-spinal tracks after the stroke (Butefisch, Kleiser et al. 2006). Control commands effectively

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transmitted to the limbs can be assessed by measuring electric potentials at the muscles (electromyogram, EMG). Depending on the brain lesion, the amount of motor control, and therefore of active movement, is compromised. To overcome this limitation, we propose a hybrid Virtual Reality (VR) and robotic approach for the restoration of correct limb pose and active movement. The objective of our hybrid system is to restore motor control of the upper limbs when active movement is compromised but weak EMG responses are still present. Hence, our technology can enable motor impaired patients to exercise movement even when active movement is severely compromised. The restoration of active movement may play a crucial role in mobilizing cortical plasticity, and therefore in accelerating recovery after stroke. First, although passive movement exercising is able to engage motor networks by means of proprio-receptive feedback (Carel, Loubinoux et al. 2000), it has been shown not to be the most effective way of engaging overt execution motor areas (Szameitat, Shen et al. 2012). Second, the activation of motor related networks does not only depend on the action intent, but also on the type of actions and their completion. It has been shown that both the observation and performance of meaningful goal oriented actions can engage additional networks such as the Mirror Neuron System (MNS), which is also known as the action recognition system (Gallese, Fadiga et al. 1996; Kohler, Keysers et al. 2002; Keysers, Kohler et al. 2003). The discovery of the MNS has allowed the emergence of novel stroke rehabilitation approaches based on clear neuroscientific hypothesis on brain recovery mechanisms (Altschuler, Wisdom et al. 1999; Ertelt, Small et al. 2007; Merians, Tunik et al. 2009; Rizzolatti, Fabbri-Destro et al. 2009; Michielsen, Selles et al. 2011). In this project, we propose restoration of active movement as a crucial step to fully engage both the motor control networks and the MNS. Therefore, by restoring active movement and engaging patients in a physical training with meaningful goal oriented actions, our hybrid system is designed to facilitate true recovery by means of cortical plasticity.

Previous myo-electric driven robotic interventions (Hu, Tong et al. 2009) have been shown to lead to improved Fugl-Meyer scores of the upper extremities (Fugl-Meyer, Jaasko et al. 1975) and reduced spasticity as assessed by the modified Ashworth score (Bohannon and Smith 1987). Many control techniques have been explored for myo-electric driven movement assistance such as Fuzzy controllers (Kiguchi, Tanaka et al. 2004) or compliant systems (Tsagarakis and Caldwell 2003; Andreasen, Alien et al. 2005). In this project, we use a unique wearable and portable orthosis with integrated myo-electric measurement capabilities that restores correct limb position (mpower1000, Myomo Inc., Boston, USA). Further, the combination of the myo-electric orthosis approach with a VR training paradigm is appropriate because of the inherent properties of VR systems for motor rehabilitation. VR approaches allow for a combination of features including: low cost; personalization of training; unsupervised training; goal-oriented actions; adaptability to a broad range of patients; quantifiable outcome measures; extended feedback; and motivation thanks to the use of game elements (see Lucca (2009) for a detailed review). Our VR training environment builds on previous work (Bermúdez i Badia and Cameirão 2012) and on training principles that we have shown to accelerate recovery in the acute phase of stroke (Cameirão, Bermúdez i Badia et al. 2011). Thus, our hybrid system exploits state-of-the-art information and communication technologies, a myo-electric robotic approach, and neuroscience based rational to provide a novel personalized rehabilitation training system that addresses the physical sequels and social impact of stroke. The approach presented here puts special emphasis on patients without or with minimal active movement capabilities and those with spasticity, enabling them to train active movement (Figure 1).

2. METHODS

In our approach, we capitalize on the use VR because it is a particularly enabling technology that can support requirements for an effective training. VR allows creating fully controlled environments that define training tasks specifically designed to target the individual needs of patients. Additionally, intensive movement training can be supported through motivating tasks that use augmented feedback and reward (see Lucca (2009) for review). Besides, our VR based rehabilitation system has been integrated in a game like interaction, capitalizing in motivational factors that are essential for recovery (Maclean, Pound et al. 2000). In addition, VR not only allows for the individualization of training and monitoring by physicians, but also enables patients to play a more active role in their rehabilitation process and be able to self-monitor their own improvements. Nevertheless, the novelty of our approach is the combination of an online adaptation of the level of assistance provided by a robotic limb orthosis with EMG measurement capability during VR training (Figure 1). This technology allows us to restore active movement, compensate for fatigue, and optimize training duration, intensity, repetition, etc.

2.1 Limb Orthosis

The mpower 1000 robotic device (Myomo Inc, Boston, USA) is a portable limb orthosis that is controlled through EMG signals that are measured by an onboard data sampler. 2 EMG channels and 1 actuated joint

are used to restore active movement based on biceps/triceps EMG activation or relaxation (Figure 1, 2–3). The mpower assists its user in the completion of arm movements by means of an embedded electric motor that is activated on the detection of biceps and/or triceps EMG activity. The EMG signals are compared to the baseline EMG activity level of the user and an assistive force – either arm extension or contraction – is executed when EMG changes – muscle contraction or relaxation – are detected. This approach makes therapy accessible to patients with no or weak active moment, but residual EMG activation, as well as to spastic patients with increased muscle tone – with involuntary and permanent EMG activation –, correcting limb position and allowing them to train active relaxation to gain movement control. The mpower connects to the virtual environment via a virtual serial port over Bluetooth, allowing its remote control from within the training environment. This wireless connection provides information on the orthosis settings, arm position, and EMG readings, as well as it allows to remotely adjust the level of motor assistance during training from 0 to 100%.

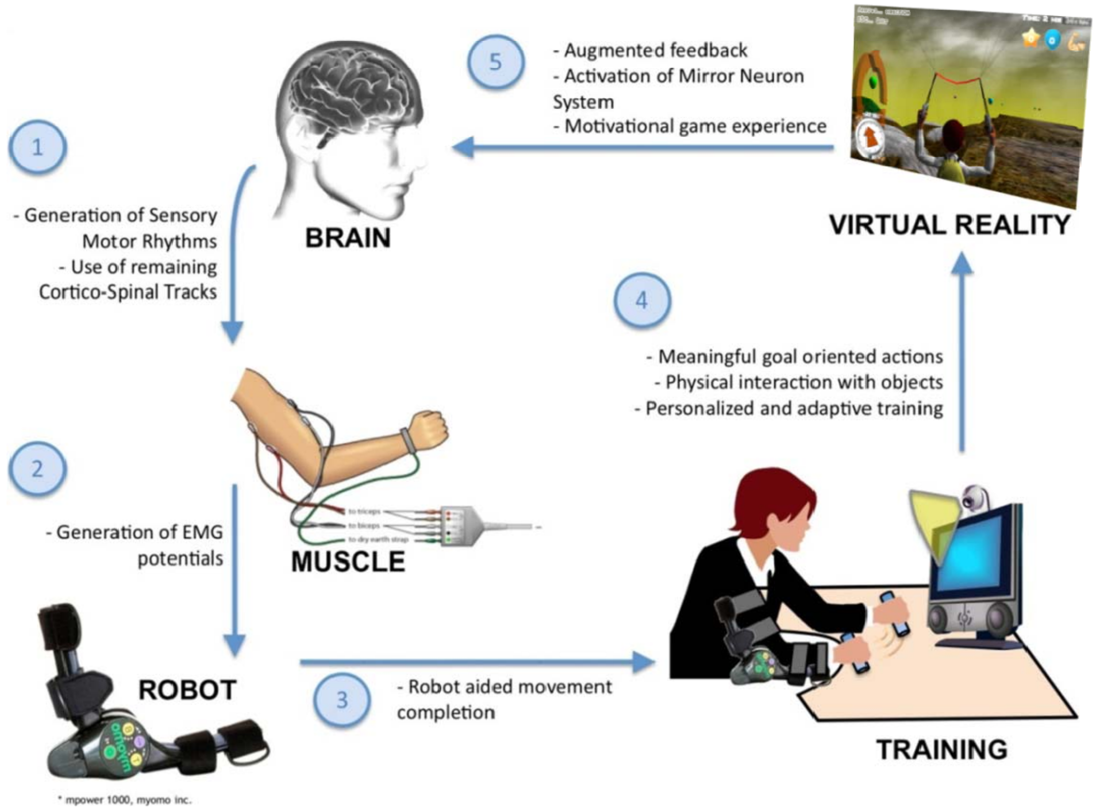

Figure 1. *Diagram of the proposed virtual reality and robotic limb orthosis training paradigm showing the role of each technological component (numbered from 1 to 5).*

2.2 Tracking

The tracking technology used in this project is the ARToolKit (ARToolworks, Inc., Seattle, USA). The ARToolKit is an augmented reality software toolkit that enables tracking the position (x, y, z) and orientation in space of predefined unique markers by using a webcam as input device. In our system, the ARToolKit was used to track two handles (7 cm diameter × 12 cm high) with unique visual markers. Consequently, users of the proposed system were instructed to grasp and move these handles around a table top in order to interact with the virtual environment (Figure 2, right panel). Thus, an overhead webcam is used to track the position and orientation of the markers, providing the virtual environment with precise information about the position and movement trajectories of the hands of the users during the training sessions.

2.3 Virtual Environment

The virtual environment and training task are based on the Neurorehabilitation Training Toolkit (NNT) (Bermúdez i Badia and Cameirão 2012). The NTT is a virtual training environment developed with the open source game engine Panda3D (www.panda.org) that was designed following neuroscientific and therapeutic guidelines for stroke rehabilitation, such as relevance of training to ADLs, neuronal mechanisms of recovery,

narrative, personalization or individualization, augmented feedback, and engagement (see (Bermúdez i Badia and Cameirão 2012) for a detailed description of the training rational). In essence, the training task is a game experience consisting of a bimanual coordination task that uses upper limb motor actions as control signals. Bimanual upper limb training tasks have been shown to enhance excitability of cortical motor networks and lead to improved functional outcomes (Stoykov and Stinear ; Byblow, Stinear et al. 2012). The bimanual motor actions are mapped onto the actions of an avatar that controls a glider in the virtual environment, i.e., the physical arm movements of the user are used to control the steering direction of a virtual glider (Figure 2, left panel). Feedback on performance and on-screen information is extensively used to inform the user on the immediate game goals and motor actions to be performed, and as reward. The goal of the game is to gather the largest number possible of collectable items in the virtual environment. Two types of collectable objects are present - easy (balloons) and difficult (stars) – that are accumulated to an on-screen score to provide feedback on performance. In addition, the amount of arm movement measured by the limb orthosis is also provided as a visual score. All tracking and training data are logged as a text file for later analysis.

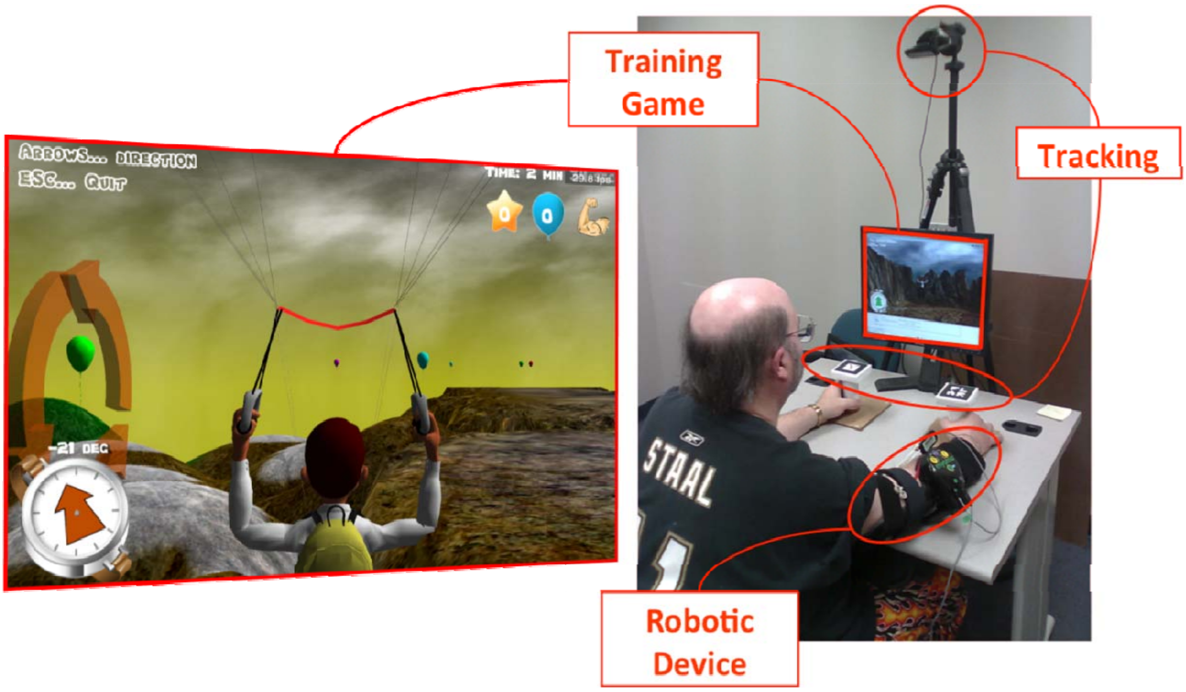

Figure 2. *Prototype of the myo-electric based interactive system for rehabilitation. Left panel: An adaptive training in the form of a game defines the training parameters for a bimanual coordination motor task. The training offers augmented feedback on performance, sustains motivation, and automatically modifies the level of motor assistance offered by the limb orthosis. Right panel: The different components of the system (robotic device, tracking setup, and training game task) while being used by a stroke patient.*

2.4 Pilot Study

The objective of this study was to assess the acceptance and usability of the system, and the impact of the level of assistance of the limb orthosis on task performance and overall arm movement. We evaluated the system with 3 chronic stroke survivors (47–63 years old; > 6 months post-stroke) in a laboratory setting at the University of Pittsburgh (Table 1). All subjects had a very low level of control of their paretic arm but were able to generate voluntary biceps EMG activation and hence drive the robotic orthosis. All subjects used the robotic orthosis in the biceps mode – only controlled by biceps EMG activity – and were asked to use the system for a single training session of approximately 20 minutes. During the training session, the level of assistance of the orthosis was randomly changed between 40 and 90% every time a virtual item was collected. After the training session, subjects were asked to report on their experience by answering a questionnaire about enjoyment, engagement and usability rated using a Likert scale from 1 to 5. All subjects gave their informed consent to participate in this study.

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Table 1. *Patients' demographics.*

Age:	47	63	50
Sex:	Male	Male	Male
Stroke type and location:	Hemorrhagic left	Ischemic left	Ischemic right
Handedness:	Right	Right	Right

3. RESULTS

This is a unique system that not only engages users in a game like training experience, but also makes use of a myo-electric capable orthosis to restore active movement. However, the effect of the orthosis assistance in movement restoration and the optimal way of integrating it in an interactive training are difficult to assess. For these reasons, we performed a number of experiments in which we exposed stroke patients to a training session of the combined virtual reality and myo-electric limb orthosis paradigm. Training data were recorded synchronously with tracking data as well as limb orthosis settings. The analysis of the combined data revealed a linear effect of the level of assistance of the limb orthosis in the amount of biceps movement during training as measured by the system in deg/s (Figure 3, left panel). The quantification of this linear relationship will enable us to integrate the virtual reality training and orthosis using statistical techniques to automatically adjust the level of assistance depending on the characteristics of each user, such as for instance the level of motor control, fatigue, or force.

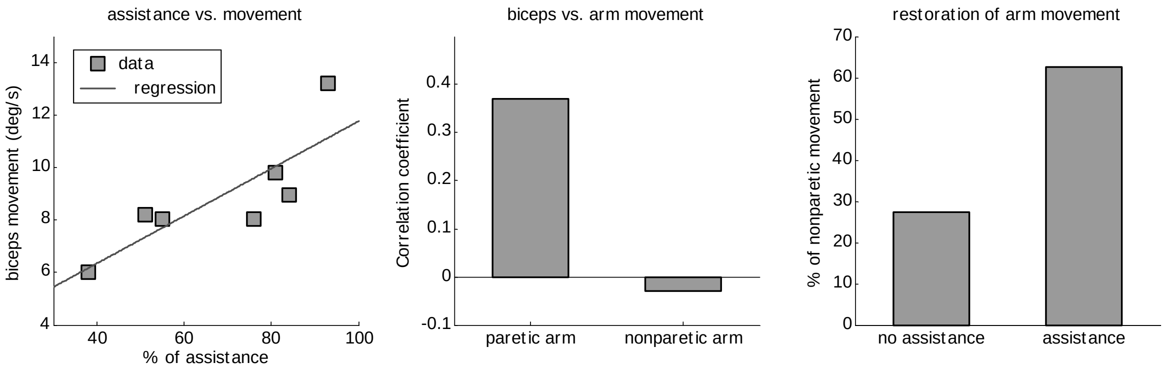

Figure 3. *Effect of the myo-electric limb orthosis during the virtual training task. Left panel: Effect of the level of assistance of the limb orthosis on the amount of biceps movement. Middle panel: Quantification of the contribution of the biceps movement to the overall arm movement, computed as the correlation value of the biceps and arm movements during training. Right panel: Restoration of arm movement. % of arm movement of the paretic arm as compared to the non-paretic arm in presence and absence of robotic assistance. Data from patient 3.*

The integrated system allows us to simultaneously measure both the movement of the arm end effector – tracked by a marker on the handle (Figure 2, right panel) – and the specific movement of the biceps as measured by the orthosis. These data are of extreme value since the particular contribution of the biceps/triceps movement to the overall movement of the arm can now be quantified (Figure 3, middle panel). In our experiment, we could assess that the movement of the limb orthosis showed a low correlation coefficient with that of the end effector (.37) that reveals a low contribution of the elbow joint – and therefore a low biceps/triceps contribution – to the bimanual control task defined in our training. This indicates that possible compensatory movements were used during training. Further, our combined limb orthosis and virtual reality training system allows us to compare differences between paretic and non-paretic arms. This enables monitoring over time the evolution of the patient using the non-paretic arm as reference. Of particular interest is the comparison of the movement capability of the paretic and non-paretic arms when the orthosis assistance is enabled. During our pilot experiment, we have quantified the impact of the active orthosis on the overall movement of the arm in patient 3 and were able to restore the paretic arm movement to about 60% of the non-paretic arm. These results are yet more remarkable when compared to the without assistance condition, in which the overall movement of the paretic arm is below 30% of the non-paretic one (Figure 3, right panel).

Questionnaire data revealed a good acceptance of the system, the most positive aspects being: fun (4.3), entertaining (4), and willingness to use it as regular motor training (4.6). Subjects reported that the system was easy to understand (3.6) but also considered it an uneasy training task (1.6).

4. CONCLUSIONS

Here we presented a novel hybrid system that integrates a VR training and a myo-electric limb orthosis. This system is an extension of the Neurorehabilitation Training Toolkit (NNT) that aims at restoring arm movement in severely affected stroke patients by integrating a portable robotic limb orthosis. In this first pilot experiment, we have successfully deployed and tested our bio-hybrid VR interactive rehabilitation system with 3 chronic stroke patients. The system was evaluated by means of quantitative behavioral data acquired by the system itself and self-report questionnaires. Initial results show that our system is capable of online adjusting the assistance level provided by the orthosis, and that the orthosis assistance has a linear effect on the overall arm movement, being able to restore up to 60% of the active movement capability. Further, our technology allows to separately assess the contribution of the biceps/triceps movement to the overall bilateral training task. This enables to objectively assess and monitor the active contribution of the elbow joint to the movement as well as that of the compensatory actions. Questionnaire data reveal a high level of acceptance of the system and its VR training task. We are currently developing an algorithm to automatically adjust the level of assistance to maximize the outcome of training. In the future, we will assess the long-term impact of these technologies in a randomized controlled trial in the inpatient rehabilitation unit (RHB) of the Hospital of Funchal.

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Serious games for physical rehabilitation: designing highly configurable and adaptable games

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ABSTRACT

Computer games have been recognized as a motivational tool in rehabilitation for a decade. Traditional rehabilitation includes exercises which are often considered as repetitive, boring and requires supervision by the therapist. New opportunities in rehabilitation have risen with the emerging popularity of computer games and novel input sensors like 3D cameras, balance boards or accelerometers. Despite active research in this area, there is still lack of available games for rehabilitation mainly due to many different requirements that have to be met for each type of therapy. In this paper we propose a specialized configurable architecture for revalidation games, focusing on neuro-muscular rehabilitation. The proposed architecture enables a therapist to define game controls depending on the patient needs and without any programing skills. We have also implemented a system meeting this architecture and four games using the system in order to verify correctness and functionality of the proposed architecture.

1. INTRODUCTION

Computer games and simulations have been recognized as a motivational tool in rehabilitation (e. g. neuro-rehabilitation, physiotherapy) for several years (Susi, Johannesson, and Backlund 2007; Hocine and Gouaich 2011; Rego, Moreira, and Reis 2010). Classic rehabilitation may include various techniques which are often predictable, repetitive and require practicing at home. Especially in case of physiotherapy and occupational therapy it is important to keep patients motivated and eventually allow them to practice at home without the constant therapist supervision.

An affordable way of developing games for rehabilitation is based on the concept of mini-games. These games can easily overcome diverse shortcomings of commercial games, often encountered when they are practiced by children with special needs (Vero Vanden Abeele et al. 2010). Mini-games can be developed and adjusted relatively quickly. Modern software tools and game engines used by indie game developers speed up the development process from years to months, weeks or even days. However, games used in rehabilitation need additional support, software tools and specialized input devices (van Loon et al. 2011). The lack of these tools makes the development rather complicated.

A huge variety of mini-games is available at low price. Each of these mini-games is usually focused on a specific exercise (Geurts, V Vanden Abeele, and Husson 2011). Consequently, researchers and developers multiply efforts to cover the most frequently used exercises. But, as long as specific hard-coded sensor input methods are used, the application field of the individual games is rather limited. Therapists must pay special attention in selecting the games for specific patient groups in terms of exercises (i.e. speed and range of motion for particular joints during specific motions) and controlling methods (Annema et al. 2010).

Many games that support configuration can only be configured partially and the usage of input sensors often remains hard-coded. In (Geurts et al. 2011) the authors describe 5 mini-games that can be calibrated

and adapted for each patient in terms of speed and accuracy. The physical exercise and the input method (in this case the sensors) are static and cannot be replaced.

Although it is reported that such games are helpful in rehabilitation (Standen et al. 2011), no (clinical) analysis at runtime is provided. Such runtime analysis during the gameplay would be helpful in order to evaluate the progress and correctness of the exercise execution and to make suggestions or to provide incentives for corrections. Besides that, data gathered and analysed in long term playing could potentially improve the doctor's information about the patient's state.

In this paper, we propose a specialized configurable architecture for revalidation games, focusing on neuro-muscular rehabilitation. We argue that this architecture increases the usability of exergames and their adaptability for both the patients and the therapists. In addition, it can make the effects of the game playing more transparent to the doctor, by providing the possibility to analyse long term playing.

2. RELATED WORK

Over the last decade, serious games for the rehabilitation have gained popularity and much research was intended to provide evidence of clinical relevance (You et al. 2005; Golomb et al. 2010; Huber et al. 2008), even in in-home use. Consequently, this research often resulted in highly specified games (Geurts et al. 2011) and only rarely with a concept behind these games, their architecture and the specific requirements. J. Perry et al. (Perry et al. 2011) described the typical workflow of such a game as a cyclic process of treatment planning, execution and performance assessment. In addition, they described the user-centric design process that should take a place when designing rehabilitation platforms based on computer games. As a result of the European project PlayMancer (Conconi et al. 2008) a robust Serious Gaming 3D Environment was presented. This environment, containing a hardware abstraction layer and a multimodal dialog manager, enables games to define multiple modalities for interaction in the 3D world. Another recent European project REWIRE, is focusing on building a cheap in-home system for rehabilitation also with an adequate set of mini-games. However, the outcome is not available yet and so it is not clear which modalities they will use and how the modalities will be combined.

3. METHODS

Our proposed design is based on discussions with therapists and patients in order to capture their ideas and fulfil their needs (Perry et al. 2011). The architecture of our system (see Fig. 1) consists of three main layers:

Game controls layer – abstracts hardware devices for the rest of the system. Each input device is represented as a module and can be connected to the system through the unified event-based interface. The modules convert input signals to the uniform format used in the rest of the system. These modules are loaded dynamically at runtime and can be changed without modifying the game even during the gameplay.

Game configuration layer – routes input signals from input modules to the games according to the configuration. This configuration enables a huge variety of possibilities for controlling the game. In addition, each connection between a game and an input module can be monitored by one or more analysers. These analysers can (*i*) track correctness of the physical actions of the patient, (*ii*) influence the score in a game, (*iii*) report measured data from input modules to the doctor (or store them for later assessment).

Games – exposes a binding point to the configuration layer. Each game has to define which elements in the game are controlled by the user. An example could be a game where one direction of a vehicle is controlled. The game itself would only expose a binding point for horizontal movement.

In the beginning, when the game starts, the system loads a configuration stored in the XML file. The configuration is created by the therapist based on the patient needs, using an intuitive user interface for customizing the game towards the needs of the patient. The file contains information about the sensor that the patient should use in order to play the game, the configuration of this sensor, game bindings (information about associations between the input values provided by sensors and the game controls) and analysers that should analyse input values from sensors. When the configuration file is loaded, the system loads an external input module which provides information about the sensor's state and creates game bindings. Then, during the game play, each input module updates the sensor state and passes it to the system through a unified interface. The unified interface guarantees that the input module can be replaced by any other module implementing the same interface (e. g. a 3D camera from one manufacturer can be easily replaced by another camera, released by another manufacturer, without a need to make changes to the game). When the system receives a new input value from the input module (sensor), it passes the value to the game and to the

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analysers depending on the configuration. The game receives a new value also with the information about which control in the game should be updated.

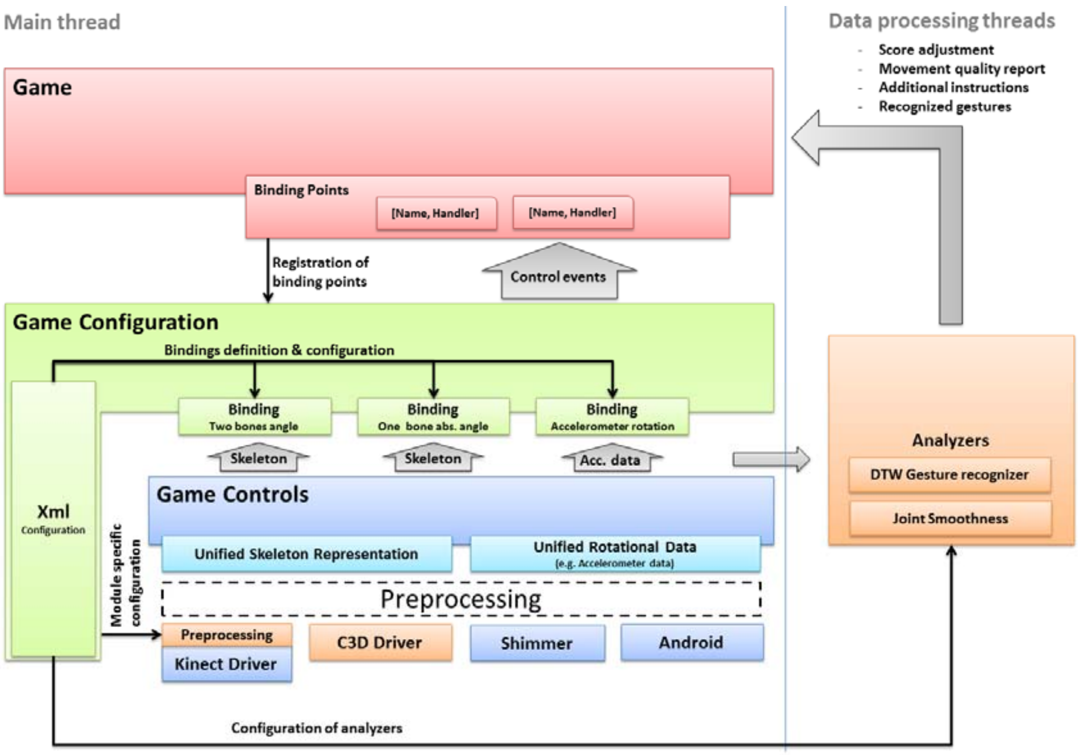


Figure 1. *System architecture.*

4. VALIDATION

In order to validate the proposed architecture we have implemented a system meeting this architecture together with four mini-games using the implemented system (for more information about these mini-games visit the project homepage www.ict4rehab.org). We have also developed a specialised configuration interface through which the therapist can set up the game specifically for each patient. In this section we describe the configuration interface and the minigames and show how they can be reconfigured with respect to the way of controlling.

4.1 Configuration Interface

Serious games have to satisfy special needs and requirements in order to be useful in the rehabilitation (Perry et al. 2011). A large number of the most critical needs, which are not available in the commercial games, can be adjusted in the system (or game) setup and configuration (e.g. calibration on the input, speed of the game). By means of this configuration, various aspects of the games can be personalized, e.g. appropriate challenge, movement analysis, input sensor or state reporting. In order to do so, we have developed a configuration interface (see Fig. 2) which enables users to configure the majority of the settings visually, without programing or designing skills.

Depending on the complexity of the information provided by the sensor (i.e. information on a single segment of the body – as for instance provided by one inertial sensor, or on more segments – as for instance provided by the Kinect), the character in the game can be controlled in more complex manners.

The supported input methods are summarized in Table 1. Each of these input methods provide only a single input value (a floating point number) to the game depending on the configuration. For instance, the game can receive the rotation angle of the specific segment of the human skeleton as a single value, and move the player according to this value. Since the values provided by a sensor might have different scales and a different offset with respect to the neutral position, the therapist can calibrate the input by setting a zero angle (or zero position) and a sensitivity value. Then, the input value y provided to the game is computed as follows:

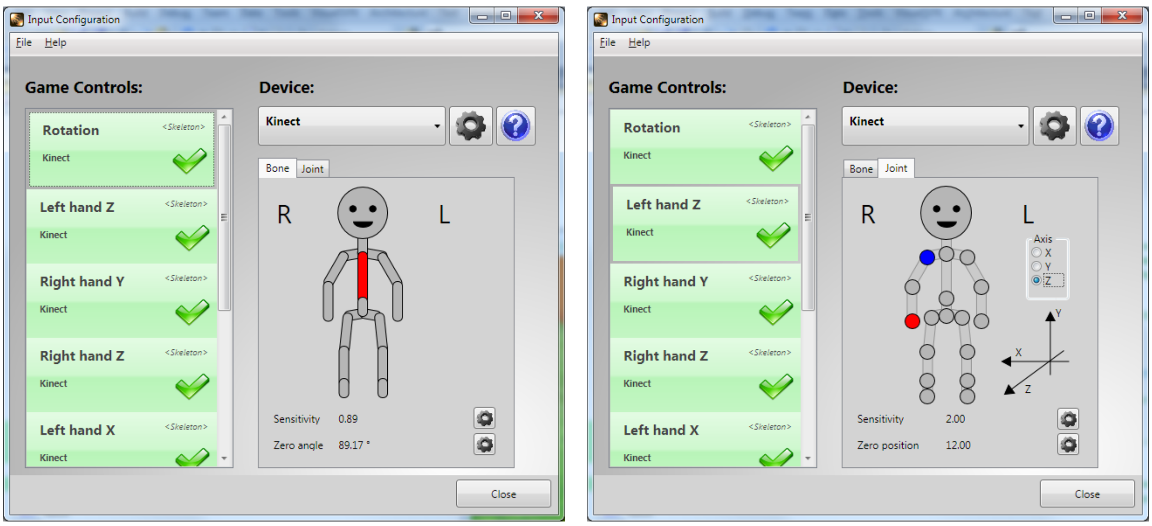
$$y = (x + z) \times s \quad (1)$$

where x is the value provided by the sensor, z is the zero position (or zero angle) and s is the sensitivity. In practice it means that the therapist might configure the position where the player doesn't move (is at the zero position) and range of the movements which the patient have to perform in order to control the game.

Table 1. *Supported input methods with sample use cases.*

Tracked property	Provided input value	Use case
Angle of skeleton segments	Absolute rotation angle of the segment (computed as the angle between the segment and the vector aiming to the left from the camera perspective)	*Horizontal movement of the player on the screen controlled by a lateral movement of the patient's trunk. The angle value is considered as absolute (it means relative to the fixed camera coordinate system), because movements of any other segment (except the trunk) have no influence on the provided angle value.*
	Relative angle between two segments	*Horizontal movement of the player on the screen controlled by the flexion/extension of the elbow. The angle value is computed as the angle between upper and lower arm regardless of the patient's body rotation.*
Position of skeleton joints	Absolute position of the joint (position provided by camera)	*Horizontal movement of the player on the screen controlled by the position of the joint in the scene in front of the sensor (camera). The task for the patient is to place the specific joint (e. g. the wrist) on a certain position with respect to the sensor.*
	Relative position of the defined joint with respect to the predefined base joint	*Horizontal movement of the player on the screen controlled by the relative position of the joint with respect to another joint (e. g. position of the wrist with respect to the shoulder). The task for the patient is to move the wrist to change the distance from the shoulder according to the selected axis.*
Accelerometer rotation	Absolute 3D rotation angle	*Horizontal movement of the player on the screen controlled by a rotation of the sensor. The patient's task in this case is to rotate the sensor according to the selected axis.*

It is important to note that even if our design allows many "unnatural" ways of controlling a game, for some people with disabilities it can be the only possible way for controlling the game. This means that games using this design could be useful not only for the mainstream therapies but also for rare cases which are currently abandoned.



a) b)

Figure 2. *Configuration interface for defining input methods for games; a) input based on the rotation of segments between joints, b) input based on the relative position of joints (red – tracked joint, blue – base joint).*

4.2 Flying Simulator

This mini-game (see Fig. 3a) is based on the widely known concept of obstacle avoidance. The game requires players to control a space ship in the horizontal direction. There are two kinds of objects, a rock and a star, approaching the ship. The player's task is to avoid collisions with the rocks and hit approaching stars.

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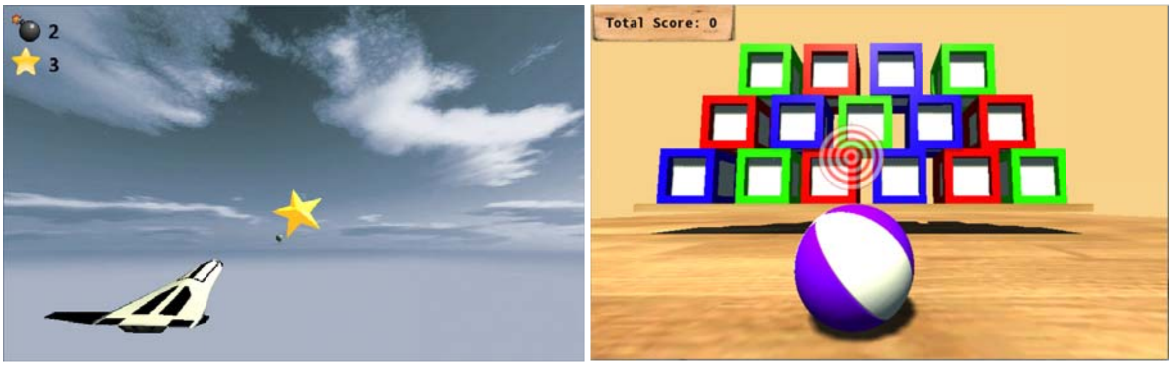
4.3 HitTheBoxes

In the second mini-game (see Fig. 3b) the main task is to control the horizontal movement of the target in front of the shelf full of boxes. There are three types of boxes with different weight and colour. In front of the shelf is also a ball which is periodically thrown after certain time. The player's task is to shed all the boxes from the shelf.



a) b)

Figure 3. *a) Flying simulator game, b) HitTheBoxes game.*

4.4 WipeOut

In the third mini-game (see Fig. 4a) the task is to clean the screen with a rag. In the beginning there is only a dirty screen displayed with the rag in the middle. The player controls the position of the rag (which is possibly bound to the position of a joint, e. g. the hand) to remove the dirt from the screen. As a reward to the player, the picture hidden behind the dirt is uncovered.

4.5 PickThemUp

In the fourth mini-game (see Fig. 4b) the main task is to pick as many mushrooms from the ground as possible. The player controls two gloves (bimanual coordination task) which are mapped to the position of his hands. In one hand (glove) the player is holding a basket. The task is to pick a mushroom from the ground (to move the other hand as close to the mushroom as possible in order to trigger collision which places the mushroom to the hand) and then put it to the basket (again, to move the hand close to the basket).

a) b)

Figure 4. *a) WipeOut game, b) PickThemUp game.*

5. RESULTS

The proposed architecture allows to easily implement a new mini-game with a specific rehabilitation objective for a specific patient group, as all core functionality is provided in a set of core libraries, separating the game input from the different sensors – and even from the regular keyboard and mouse.

We have implemented four different mini-games based on this architecture. Currently we are testing our games with children suffering from cerebral palsy (CP) in order to prove all aspects of the proposed

architectural concept and to obtain feedback from clinicians. The testing stage is crucial to the success of the system development and it is essential to be able to contribute fully to the medical community.

As a consequence of the architectural design of our software framework, the developed mini-games will also improve on the current state of the art with respect to rehabilitation schemes: (1) the games can operate with a large range of input sensors (including Kinect and other 3D cameras, accelerometers, balance boards, keyboard, …); (2) the physiotherapist can specify the combination of joints used to control the character (for instance people bound to a wheelchair can “jump” using their arms); (3) the sensitivity of the game to posture changes can be specified (i.e. the difficulty level); (4) the visual complexity of the scene can be configured (cf. cognitive visual impairment in cerebral palsy); (5) real-time simple biomechanical analysis is performed such that the targeted postures cannot simply be mimicked; (6) all these different aspects can be analysed and configured remotely by the physiotherapist.

6. CONCLUSION

In this article, a novel configurable architecture for revalidation games was presented. The architecture was designed by considering its suitability and requirements – usability, functionality and acceptability (Perry et al. 2011). We have implemented a system that meets the proposed architecture together with four games. These games have been tested with children suffering from CP and with their therapists. During these tests we observed a significant potential of our approach for building serious games and a positive feedback from both, patients and therapists. We have also observed several limitations that outline our future work.

Even though we provide the specialized configuration interface for defining various input methods visually, setting all parameters is a time consuming task. Moreover correct values of parameters vary depending on the specific game. In order to make it even easier to use, we are working on a collection of pre-defined configurations, covering selected exercises in the CP rehabilitation.

Playing these mini-games appears to be a real motivation for users, but it should be a therapy in the first place. Sensors should provide accurate measurements to assess the correctness of exercises and to make the gameplay (and background analyses) clinically relevant.

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Developmental cognitive neuroscience perspective on motor rehabilitation: the case for virtual reality-augmented therapy

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ABSTRACT

Developmental disorders and disabilities affecting movement can have far reaching, longer-term consequences for the child and their family, and present a great challenge for intervention. In the case of upper-limb function, in particular, poor compliance and use of repetitive training routines can restrict progress. In this paper we consider how an understanding of the neurocognitive bases of disorders like cerebral palsy and Developmental Coordination Disorder (DCD) can inform the choice of therapeutic techniques. Using a cognitive neuroscience approach, I explore the hypothesis that *motor prediction* is a common, underlying issue in these disorders. I then discuss the role that feedback-based and predictive control plays during the course of normal development and highlight recent applications of *augmented feedback* (AF) in motor therapy. Critically, VR-based technologies afford many options for the provision of multisensory AF. I describe recent examples of this principled approach to treatment, and conclude by suggesting avenues for future development in VR-assisted therapy.

1. INTRODUCTION

The effects of brain dysfunction and injury during childhood have profound developmental consequences for the child and place a significant socio-economic burden on families and the community (Penn, Rose, & Johnson, 2009). In the case of cerebral palsy and problems of development like Developmental Coordination Disorder (DCD), the movement difficulties present a huge challenge for therapists (P. H. Wilson, 2005). The choice of therapy must at once enable therapists to engage the child in the process of treatment, while also maximising the strength of treatment effects in what is often a limited window of time in a clinical setting. The holy grail for therapists is to find a therapeutic modality that will yield quite generalised effects on movement form and functional skill.

A principled approach to rehabilitation of manual function has been particularly slow to evolve. Most interventions for children with neurological disorders require intensive practice (e.g., Constraint Induced Movement Therapy—CIMT) and/or have poor patient compliance (Jannink et al., 2007). By comparison, virtual-reality (VR) based treatments afford new options for engaging children, maintaining their level of motivation, and for providing a set of scalable movement tasks that utilise real-time feedback. VR-augmented therapies have been applied successfully in adult movement rehabilitation, however, a systematic approach to rehabilitation in children is yet to evolve (Green & Wilson, 2012; Henderson, Korner-Bittensky, & Levin, 2007).

In this paper, I present a new model for movement rehabilitation of children with motor disorders including cerebral palsy and Developmental Coordination Disorder (DCD), a form of severe movement clumsiness in childhood. From the perspective of *developmental cognitive neuroscience*, I examine our current understanding of the key concepts of predictive control and multimodal integration. I will show these concepts to be pivotal in re-conceptualising our approach to motor intervention. In doing so, I will highlight principles underlying the use of multimodal, *augmented feedback* (AF) in therapy, and explain how VR-based systems are the ideal vehicle.

2. THE DEVELOPMENT OF MOTOR CONTROL

I present a conceptual model for the use of AF in VR-based therapy. A critical task of motor learning and development is the child's ability to extract (implicit) knowledge of the dynamics of their own motor system (Hyde & Wilson, 2011a, 2011b). More precisely, the child must learn the systematic relationship between

their own motor output commands and the effects that these commands have on the physical system; this knowledge enables predictive control, an aspect of internal modelling (Shadmehr, Smith, & Krakauer, 2010). Mature reaching is now thought to be controlled by an integrated system of feedback and feedforward control. This system enables the performer to adjust rapidly in real time to changing environmental constraints, like a moving target, with some movement parameters (like trajectory) changing in as little as 70-80 ms. The ability to implement such changes is only viable to the extent that the nervous system can predict the future location of the moving limb using a *forward (internal) model* (Desmurget & Grafton, 2003). This flexibility is one of the hallmarks of skilled motor behaviour, and develops gradually over childhood (Hyde & Wilson, in press).

That predictive control develops rapidly over childhood has been shown in a range of contexts including force adaptation (Konczak, Jansen-Osmann, & Kalveram, 2003), isometric force control (Smits-Engelsman, Wilson, Westenberg, & Duysens, 2003), anticipatory postural adjustments (Hay & Redon, 1999), and rapid online control of reaching in response to visual perturbation (Hyde & Wilson, in press). Critically, during middle childhood we see a transition in motor control, with greater reliance on visual feedback, accompanied by longer movement times but not enhanced accuracy (Bard, Hay, & Fleury, 1990; Chicoine, Lassonde, & Proteau, 1992). In later childhood we see a more mature integration of feedback and feedforward control, speeding target-directed responses and improving accuracy.

One important feature of the mature motor system is the ability to adapt movement seamlessly and efficiently in real time while maintaining speed and accuracy (Shadmehr & Krakauer, 2008). Hyde and Wilson (Hyde & Wilson, in press), for example, have shown that younger children are slower to adjust their reaching to visual perturbation than older children, suggesting a reduced ability to integrate predictive estimates of limb position with online feedback. For static targets, the movement times of older children (8-12 years) were around 550 ms and increased to around 800 on trials when the target jumped at movement onset. By comparison, the relative increase for younger children aged 5 to 7 years was significantly greater, from around 640 to 1030 ms. Moreover, younger children took longer to correct their movement trajectory on jump trials. These online corrections are thought to involve *internal feedback loops* which enable the seamless integration of predictive error signals with ongoing motor commands (Dubrowski, Bock, Carnahan, & Jüngling, 2002; Van Braeckel, Butcher, Geuze, Stremmelaar, & Bouma, 2007). Indeed, there is strong evidence that visual feedback is used to control reaching throughout the reaching cycle (Saunders & Knill, 2003, 2005) rather than simply towards the end of movement—path corrections are evident within 70-100 ms following target jumps, at least in healthy adults. In short, this process of rapid online control develops rapidly over childhood and is quite well developed in older children (Lhuisset & Proteau, 2004).

3. DEVELOPMENTAL MOTOR DISORDERS: THE CASE OF DCD AND CP

In the case of DCD, there is converging data to show that these children have a fundamental deficit of motor prediction, necessitating a reliance on slower, feedback-based control (Hyde & Wilson, 2011a). This accounts for the generally more laboured and inefficient movement patterns we see in this group. In the case of CP, the motor deficits extend to movement initiation as well as prediction (Green & Wilson, 2012).

3.1 Developmental Coordination Disorder

Deficits of motor prediction in children with DCD are evident across a range of tasks, performed under different spatial and temporal constraints. These have included sequential eye movements (Katschmarsky, Cairney, Maruff, Wilson, & Currie, 2000), visual tracking (Langaas, Mon-Williams, Wann, Pascal, & Thompson, 1998), coupling of grip and load force during lifting (Pereira, Landgren, Gillberg, & Forssberg, 2001), visually-guided reaching (Wilmut & Wann, 2008), and visual-motor adaptation (Kagerer, Bo, Contreras-Vidal, & Clark, 2004). Of the first listed example, performance on a double-step saccade task (DSST) is particularly instructive. Here children were required to make eye movements to two targets presented sequentially, the first target for 140 ms and the second for 100. Because the second target is extinguished before initiation of the first eye movement, the performer must use a forward estimate of the end position of the first saccade in order to then generate a motor command that will enable "capture" of the second target (Heide, Blankenburg, Zimmermann, & Kömpf, 1995). Intriguingly, children with DCD are as accurate as typically developing children for the first eye movement, but significantly less so for the second. This pattern of performance underlines a basic deficit of prediction in children with DCD which may be attributable to immaturities at the level of parietal cortex and its reciprocal connections with the cerebellum.

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3.2 Cerebral Palsy

Children with cerebral palsy (or spastic hemiplegia) show fundamental deficits in not only the ability to execute movements but also in movement representation and planning (Mutsaarts, Steenbergen, & Bekkering, 2006; Steenbergen & Gordon, 2006). The planning issues are manifest, among other things, in the ability to imagine how a prospective action will unfold (aka *motor imagery*). This facility to anticipate the spatiotemporal unfolding of an action (without execution) has been assessed using mental rotation tasks involving pictorial representations of body parts (like hands or whole-body stimuli). Steenbergen et el. (Steenbergen, van Nimwegen, & Crajé, 2007) tested both left- and right-sided hemiplegic patients and found that while there was no group difference between patients and healthy controls on accuracy or the timing of responses, the hemiplegic patients were generally slower. They concluded that the patients were not adopting an egocentric frame when making responses but rather used a more visually-mediated strategy. Similar results have been shown for children with CP (Williams et al., 2011). Taken together, poor motor imagery in CP seems to reflect a core deficit in the ability to generate (forward) internal models of movement. This argument is supported by neuroimaging data showing overlap in the neural networks that support both motor imagery and predictive control (De Lange, Hagoort, & Toni, 2005).

4. IMPLICATIONS FOR TREATMENT: AUGMENTED FEEDBACK AND ATTENTIONAL TRAINING

A critical part of the motor learning process is use of feedback as a means of comparing the executed action with the intended outcome of a movement. In typical learning over repeated trials, we see a gradual reduction in the discrepancy between the two. In atypical motor development, sheer repetition does not necessarily translate into improved motor skill; this is evident in both severe DCD and CP. Moreover, in the case of CP, the mechanisms by which sensory information is processed may be compromised, which further compounds the ability to implement error correction and predictive control. Importantly, methods of augmented feedback have been shown to benefit both populations, with multisensory (extrinsic) feedback and techniques that cue attentional focus being shown to exert good treatment effects (van Dijk, Jannink, & Hermens, 2005; VanVliet & Wulf, 2006).

4.1 Augmented Feedback

External (or augmented) feedback (AF) involves providing information about the performance of an action, over and above that available to the performer’s own cognitive and sensory-motor systems. In other words, the external information is additional to the naturally-occurring (or intrinsic) sources of input. There are several basic forms of AF: *knowledge of results* (KR), *knowledge of performance* (KP), and *concurrent AF*. KR involves the provision of information about the outcome of a movement (e.g., percentage success after a set of trials), while KP concerns the manner in which the movement was performed and its form. Concurrent AF involves the provision of real-time feedback, most often in the form of correlated visual, haptic, or auditory input. The benefits of various forms of AF (relative to no AF) have been well documented in the mainstream motor learning literature (Gordon & Magill, 2012; Magill, 2010). For example, AF has been shown to aid the development of coordination on rhythmic tasks, increasing stability. This is provided that multisensory information is presented synchronously with the key movement transitions (Carson & Kelso, 2004)—e.g., flexion-extension movements of the fingers, timed to an external auditory, haptic, and/or visual stimulus.

The case for AF in the rehabilitation of brain injury has also been made in a number of authoritative reviews (van Vliet & Wulf, 2006; Winstein, Wing, & Whitall, 2003). However, the quality of evidence has varied quite significantly across studies (van Dijk, et al., 2005). In van Dijk’s systematic review, no conclusive evidence was found for the effectiveness of AF on upper-limb function. However, frequently omitted from these studies was crucial information about the specific form of feedback used, adequate follow-up assessments, and very few studies used RCTs. A narrative account by van Vliet (2006) suggested more positive effects on different aspects of motor function. However, similar to van Dijk, there were a number of outstanding issues in the literature, including the relative effect of visual, verbal, video and kinematic feedback, and the types of task scheduling that yield stronger effects.

4.2 Attentional Training

The mainstream literature has provided some interesting insights into the use of AF and how it best directs the performer’s attention. The work of Wulf and colleagues (Wulf, Chiviacowsky, Schiller, & Toaldo Gentilini Ávila, 2010; Wulf, Shea, & Lewthwaite, 2010) has been most influential in showing the benefits of an external focus of attention during skill acquisition, both in adults and children (Wulf, Shea, et al., 2010).

That is, external cues are provided that encourage the performer to focus on the effects of their movement (e.g., trajectory), rather than their internal state or somatic sensations. Importantly, it does not appear to be the case that performers become excessively reliant on such cuing to the point where performance declines once it is removed (Wulf & Shea, 2004). Indeed, performance on retention and transfer tasks has been shown to be superior after external focus training than internal focus (Wulf, Shea, et al., 2010). More fundamental work has also shown that concurrent AF which biases attention to the effect of the movement yields stronger training and retention effects than feedback about movement form (Todorov, Shadmehr, & Bizzi, 1997; Wulf & Prinz, 2001).

From a cognitivist perspective, the advantage of taking an external focus of attention has been explained by increased automaticity in motor control—aka the *constrained action hypothesis* (Wulf, McNevin, & Shea, 2001). Put simply, the external focus allows the performer to enlist rapid control processes, including the ability to implement online adjustments. By comparison, switching attention to internal states and body position may encourage greater focus on the *self* and perhaps self-evaluation, which may interfere with the unconscious flow we associate with skilled performance. A more detailed account of underlying control processes has proved elusive from a purely cognitivist perspective.

Ideas encapsulated in the *ideomotor theory* of Prinz and colleagues has been more influential, drawing on neurocomputational models of action (Hommel, Müsseler, Aschersleben, & Prinz, 2001; Prinz, 1997). This states quite simply that actions are controlled by their intended effects. Ultimately, the performer learns to predict action effects in advance, with this predictive model used as a template against which actual feedback is compared. As such, the prediction is used to monitor how well an executed action matches its intended trajectory and goal outcome. Action is most efficient, therefore, when planned according to intended effects or outcomes, rather than internal states (Wulf, Chiviacowsky, et al., 2010). The use of AF that helps direct attention to movement effects is, thus, a more powerful medium for skill development and rehabilitation than other forms of feedback.

With respect to motor rehabilitation, there has been relatively little research that has examined the differential effects of adopting an internal or external focus of attention. However, there is some suggestion from cognate research that the advantages of external focus also apply to brain damaged patients (Piron et al., 2007; van Vliet & Wulf, 2006). For example, in cases where predictive control has been disrupted (through brain damage or developmental immaturity), provision of concurrent AF has been shown to assist recovery of upper-limb function (Quaney et al. 2010). What is sobering, then, is that the vast majority of verbal instructions made by movement therapists to patients in clinical settings are related to body movements and sensation, and are likely to induce an internal focus of attention (Durham, Van Vliet, Badger, & Sackley, 2009).

5. RECENT EVIDENCE SUPPORTING THE USE OF VR-ASSISTED AUGMENTED FEEDBACK

Understanding the mechanisms of normal motor development and those disrupted in CP and DCD has important implications for the choice of therapy. AF, presented using various sensory modalities in real time, can greatly leverage the development of skill in these children. Virtual-reality based systems are the perfect vehicle for this treatment, the *Elements VR system* being a recent example (Mumford & Wilson, 2010; Peter H. Wilson et al., 2007)—see Figure 1. This system targets upper-limb function using a series of tangible user interfaces (TUIs), camera-based tracking, and interactive tabletop workspace. Both goal-directed and exploratory manual tasks are employed using various forms of concurrent AF. The goal-directed tasks are cued from within the virtual workspace, with each form of AF used to reinforce one or more of three outcome parameters (speed, accuracy, and efficiency). Wulf and colleagues have also identified how AF can be used to target particular movement parameters in this way (Wulf & Prinz, 2001; Wulf, Shea, et al., 2010). For exploratory tasks, children can create their own visual and aural compositions by manipulating the TUI; for example, coloured trails – one form of AF – are composed as objects are moved across the display. In general, the AF serves two main purposes: First, it provides children with additional feedback about the outcomes of their actions; this reinforces the child's sense of position in space and of the relationship between motor command and the resultant action. We argue that this process helps train predictive (or forward) models for action. Second, AF enables the child to focus their attention on the effects of their movement, rather than on the movement itself (Wulf & Prinz, 2001). This has been shown to be leverage skill development during the early phases of learning and during rehabilitation.

A number of studies now support the argument that VR-based systems are an ideal medium through which AF can leverage the development of motor skill in children with movement disorders. The Elements system, for example, has recently been evaluated in childhood CP using a multiple case study design (Green

& Wilson, 2012). Four children with non-progressive hemiplegia participated in 30-min sessions daily for 3-4 weeks. During training, each child was instructed to focus on a type of concurrent AF that was appropriate to the performance variable that was targeted. For example, if the aim was to improve accuracy, the child was instructed to focus on "disk AF" which consisted of an increase in the luminance of the target as the TUI approached it. Children engaged well with the system, found it intuitive to use, and derived reward from the movement-dependent AF. Critically, training saw considerable improvement in the motor skill of children with quite severe CP. This supports earlier work in adult patients with TBI (Mumford & Wilson, 2010). Methods to test the hypothesis that improved predictive control underlies these changes are under current investigation.

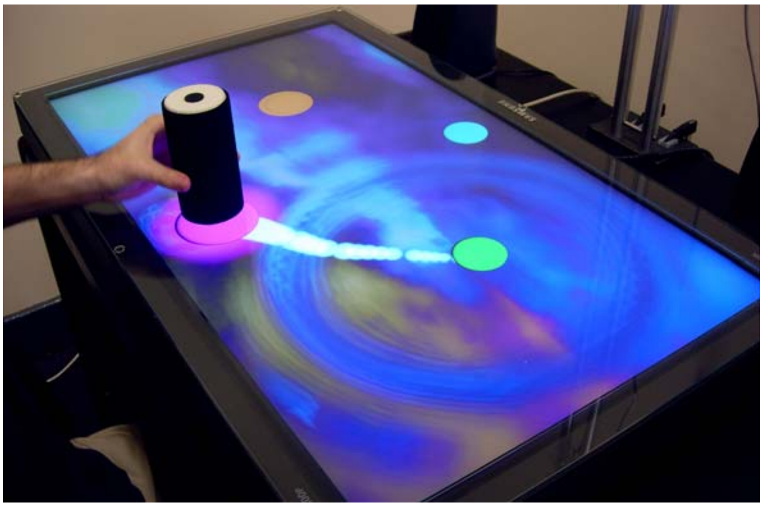

Figure 1. *Sample display from the Elements system: Goal-directed task including (visual) augmented feedback.*

6. CONCLUSIONS

A principled approach to VR-augmented rehabilitation is only possible to the extent that we fully understand the neurocognitive underpinnings of childhood disorders like CP and DCD. A review of the literature suggests that predictive control is one pivotal component of the motor system that is frequently disrupted in children with these disorders. Predictive control is implemented using a distributed system of cortical and sub-cortical structures including the cerebellum, posterior parietal cortex and their reciprocal connections to frontal motor cortices. Critical to predictive control is the performer's ability to construct (or re-construct) the systematic relationship that exists between motor command signals and their anticipated effects on the physical system. Implicit knowledge of this relationship underpins the use of forward internal modelling as means of rapid online control, for example (Desmurget & Sirigu, 2009). Intriguingly, AF is one treatment modality that may foster the development of this ability in children with motor problems. More specifically, concurrent AF (which also encourages an external focus of attention) has been shown to be particularly effective when implemented using VR-based systems. The Elements system, for example, has used a combination of aural and visual AF to leverage the recovery of children with not only CP, but also childhood stroke and other congenital disorders affecting movement (Green & Wilson, 2012).

Our use of the term *VR-augmented therapy*, thus, takes on a dual meaning: it suggests both the promise of VR in leveraging rehabilitation in children, as well as its possibilities as a medium for providing AF. We suggest that multisensory AF is a particularly powerful way of encouraging children to learn (or re-learn) movement skills. Part of this learning process involves the gradual re-construction of the child's body schema and the ability to anticipate the outcomes of its interactions with a 3D environment. Exactly what aspects of AF (and their combination) yield the strongest training effects is a prime issue for investigation, as is the extent to which functional gains are correlated with the ability to use predictive control. Future research in this area will inform not only the clinical application of VR technologies, but also our basic understanding of the motor control and learning system.

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Assessing prospective memory in young healthy adults using virtual reality

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ABSTRACT

Virtual Reality (VR) is a very relevant tool for the study of complex cognitive functions, such as Prospective Memory (PM; remember to execute an intention at an appropriate time in the future). Thirty-five young subjects performed a PM task while immersed in a virtual city. On a theoretical level, we reached a better characterisation of PM functioning, notably regarding the influence of the link between the “when” and “what” components of PM on performance in event- and time-based PM tasks. This work validates utility of VR in PM assessment and opens perspectives in evaluation and rehabilitation of PM deficits.

1. INTRODUCTION

Studies of episodic memory have long been confined to its retrospective dimension, defined as the ability to recall past events. Over the last 20 years, a growing number of studies have focused on its prospective dimension. Prospective Memory (PM), defined as the ability to remember to execute intentions at some point in the future (Einstein & McDaniel, 1990), is a multi-determined construct underlying processes which remain poorly understood. PM implies forming an intention, maintaining this intention during a delay filled by another activity and, at the appropriate time, reinstate the intention and switch from the ongoing activity to execute it (Kliegel, Martin, McDaniel & Einstein, 2002; McDaniel & Einstein, 2007). A first dichotomy concerns event-based PM (EBPM) and time-based PM (TBPM). For EBPM, intention execution is triggered by the appearance of an external event (e.g. remember to take the cake out of the oven when the timer will ring), while for TBPM, intention execution has to be auto-initiated by the subject after a predetermined time interval (e.g. remember to take the cake out of the oven after 30 minutes or at 4.15 pm). A distinction is also done between the Prospective Component (ProCom) of PM, which refers to remembering that something has to be done, and the Retrospective Component (RetCom) of PM, which refers to the content of the intention (i.e. what has to be done; Einstein & McDaniel, 1990).

It is easy to imagine that impaired PM may have significant implications in daily life and cause professional and social difficulties as well as potentially dangerous situations (e.g., forgetting appointments, to turn off the oven, to take medication or to send an important message). A better understanding of PM is useful since it is subjected to numerous complaints, both in normal and pathological aging (Smith, Della Sala, Logie & Maylor, 2000). Consistently, deficit in PM has been found in healthy aging, since middle-aged (Gonneaud, Kalpouzos, Bon, Viader, Eustache & Desgranges, 2011; see McDaniel & Einstein, 2011 for review) and in several neurological pathologies, as traumatic brain injury (Shum, Levin & Chan, 2011 for review), multiple sclerosis (Rendell, Jensen & Henry, 2007), Parkinson’s disease (Kliegel, Altgassen, Hering & Rose, 2011), mild cognitive impairment (Costa, Caltagirone & Carlesimo, 2011) or Alzheimer and vascular dementia (Livner, Laukka, Karlsson & Bäckman, 2009). Distinction between EBPM and TBPM has frequently been performed and showed that TBPM seems to be more sensitive to healthy aging and pathology than EBPM, because it requires higher amount of controlled processes to monitor the time and initiate retrieval of intention (Craik, 1986). A common theory of PM, the Multiprocess Theory (McDaniel & Einstein, 2000), suggests that PM requires processes ranging from automatic to controlled, depending on the characteristics of the task. One of the situations allowing automatic retrieval of intentions is when the PM cue

and the intended action are strongly associated (McDaniel, Guynn, Einstein & Breneiser, 2004). It is then assumed that in such situations, the mere perception of the PM cue brings reflexively the intended action to awareness. As a result, a lack of link between ProCom and RetCom, particularly in TBPM situations where such phenomenon is scarce, may account for the difficulties of retrieval in PM.

PM has been studied using either tasks performed in a natural environment or experimental controlled tasks, and results are often different according to these two types of measures. In naturalistic situations, subjects are for example asked to call the experimenter once a day for several days (Maylor, 1990). In laboratory, subjects are engaged in a cognitive task (i.e. ongoing task such as verbal memory span) and are asked to remember to give an additional answer (e.g. press a key) in response to specific items or after a certain amount of time has elapsed (Einstein & McDaniel, 1990). Both have been criticized, the former because of a lack of control, and the latter because those tasks do not allow an accurate assessment of PM. Moreover, studies on healthy aging have highlighted an "age-prospective memory-paradox" with higher performance of PM in elderly subjects compared to younger in natural settings and lower performance in laboratory evaluation (Schnitzspahn, Ihle, Henry, Rendell & Kliegel, 2011). Virtual reality (VR) seems to be a promising way to assess cognitive functions and overcome methodological limitations of standard assessments by increasing experimental control in naturalistic settings (Knight & Titov, 2009). It is particularly interesting in complex situations such as memory ones (Plancher, Gyselinck, Nicolas & Piolino, 2010; Plancher, Tirard, Gyselinck, Nicolas & Piolino, 2012), and more specifically PM ones. VR has recently been used conclusively to assess PM in patients (Brooks, Rose, Potter, Jayawardena & Morling, 2004; Kinsella, Ong & Tucker, 2009; Sweeney, Kersel, Morris, Manly & Evans, 2010) or to explore theoretical views (Kalpouzos, Eriksson, Sjölie, Molin & Nyberg., 2011). Indeed, VR allows us to test the implication of cognitive processes during a realistic PM task, without all the logistical problems that entails real-life situations. Additionally, while laboratory paradigms are quite stereotypical (i.e. press the "Y" key whenever you encounter the word "president"), the use of VR gives us the opportunity to increase the variety of intentions, and to obtain many more measurements.

Using VR, we aimed to assess the impact of the links between the ProCom and the RetCom on the EBPM-TBPM distinction, manipulating the strength of the link between the target cue and the intended action in EBPM (Link versus no-Link). Our hypothesis was that a lack of link between ProCom and RetCom in TBPM tasks makes them harder to perform than EBPM tasks. Thus, TBPM performance should be worse than EBPM performance only when the link between the EBPM cue and the intended action is strong. Moreover, we wished to highlight the cognitive processes involved in EBPM and TBPM, respectively, and expected implication of distinct processes according to the nature of PM tasks, as previously suggested in one of our studies (Gonneaud et al., 2011) using a laboratory device.

2. METHOD

2.1 Subjects

Thirty-five healthy subjects aged from 18 to 40 (mean age = 24.80, standard deviation = 5.70; 12 women and 23 men) were recruited. All subjects were French-native speakers and 34 were right-handed (the last one was left-handed). We ensured that subjects had no antecedent of neurological or psychiatric disorder and had at least seven years of schooling (mean years of schooling = 14.20; standard deviation = 2.35) and a driving licence. The study was approved by the regional ethics committee.

2.2 Virtual environment

Virtual environment used in this study was an urban environment, where subjects could navigate using a virtual car (see Figure 1 for caption of the virtual environment). To do so, they had at their disposal a real steering wheel and two pedals (a gas one and a brake one). Experimentations took place in a room dedicated to virtual reality at the CIREVE (Interdisciplinary Centre of Virtual Reality, Caen, France). Virtual environment was run on a PC laptop computer and projected on a 180 x 240 cm widescreen. Each subject was tested individually and comfortably installed at approximately 300 cm of the widescreen. The virtual environment was built with Virtools Dev 3.0 software (www.virtools.com; see Plancher et al., 2010; 2012 for description of the virtual environment).

For the purpose of this experiment, two cities were created. A first city, used for the familiarisation stage, was a neutral environment including ordinary buildings (all of them were similar), some trees and interactive traffic lights in order to force subjects to use the pedals. There was only one road, forming a loop to allow the subjects to navigate in the environment as long as they needed until they felt confident with the device. The second city, the city of interest, was used for the learning and PM stages of the experiment (see Figure 2 for

the map of this virtual town). This one was a one-road town, including various buildings, traffic lights, stores, trees, hoardings, parked cars and walking people. More particularly, there was a news kiosk, bus stops, a parking lot, a fountain, a post office and a city council. These elements were used in the PM stage as EBPM cues. They were located so that they can be easily detected (i.e. in front of subjects in the turns or quite salient on the side of the road; see Figure 1 for an example of EBPM cue). To avoid involvement of spatial memory or orientation ability, there was only one possible road through the town, leading to the train station (signalling the end of the experiment). In addition to the visual environment, an auditory urban background was added to reinforce the immersion of subjects during the experiment. Finally, subjects had an external clock to monitor the passage of time. This clock was positioned so that the subjects had to voluntarily turn their look to the clock in order to monitor the time.

Figure 1. *Virtual Environment: figure on the left displays caption of subjects' point of view during the experiment; figure on the right is an example of EBPM cue (i.e. buy a diary at the City Council).*

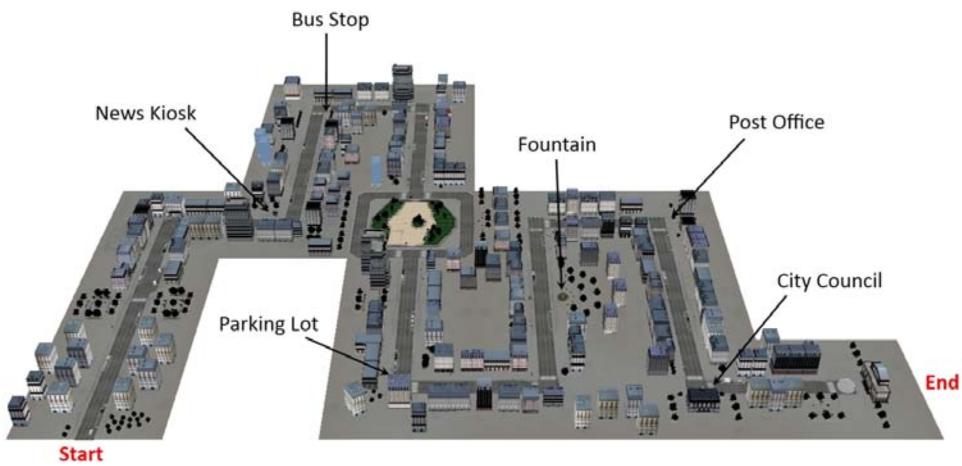

Figure 2: *Map of the city (departure on the left, arrival on the right).*

2.3 Procedure

2.3.1 Familiarisation with the device. At the beginning of the session, subjects were familiarised with the device in order to avoid difficulties in the memory test which would be due to the use of a new material. To do so, subjects were immersed in the first city (i.e. familiarisation city, see above). They were informed that there was nothing special to look into this environment. They only had to learn to use the wheel and the pedals so that they could not focus on driving and be able to do something else simultaneously, like memorising what surrounding them. They could drive as long as they needed to feel confident.

2.3.2 Learning stage of the city of interest. This first immersion in the city of interest aimed to ensure that participants could easily detect and recognise important elements for the PM task (i.e. EBPM prospective cues). As a result, once subjects felt confident with the virtual device, they were told they will be immersed in another city, more elaborated with various buildings, pedestrians, hoardings…. This second city was composed of a single road leading to the train station. Subjects were asked to follow this road, respecting the

highway road, while paying attention to the elements they encounter along their way, so that they could thereafter recognise pictures of the elements which were part of this city among elements which were not part of it. In addition, subjects were informed that they had all the time they needed to navigate through this city, but that they could not turn back.

At the end of this first immersion in the city of interest, a recognition test was proposed. Participants had to recognise 14 old elements among 22 (eight new) elements. Six of the old elements were the cues of the EBPM task. Feedbacks were given to subjects and, for each element that was not recognised, they were informed about its location in the city using a map of the town.

2.3.3 PM task in the virtual environment. Once subjects were familiarised with both the device and the city of interest, we told them that we were also interested in their ability to remember doing something at some point in the future. Thus, participants were warned that they will again be immersed in this city to go get a friend at the train station. On the way leading to the train station, they will have a series of actions to perform. To do this, they must initially learn these nine intentions and, when they will be again immersed in the city, remember to perform all these actions at the appropriate time.

- *Encoding of intentions.* The nine intentions were presented to subjects on the screen of an additional PC laptop. Each intention was presented on the screen for ten seconds. Six intentions were EBPM: for half of them there was an evident link between ProCom and RetCom (Link-EBPM; e.g. buy stamp booklet at the post office), while for the other half it was not the case (noLink-EBPM; e.g. buy eyeglasses at the fountain), and three intentions were TBPM (e.g. take medication after 4 min). To ensure that PM failures were not due to a deficit in encoding, a cued recall test was proposed to subjects just after the presentation of the nine intentions (e.g. what do you had to do at the post office?) and unrecalled items were repeated until they were correctly encoded. After that, subjects were asked to predict prospectively their ability to perform the task later on a five-point Likert scale (from 1: not at all, to 5: perfectly).
- *Storage of intentions.* There was a 10 minutes delay between the encoding and the retrieval of intentions, filled by distractive tests (i.e. questionnaires).
- *Retrieval of intentions.* After the 10 minutes delay, subjects were again immersed in the city of interest. They were reminded that they should get a friend at the train station and that they had several things to do on their way. To do so, they had to stop the car at the appropriate time or place, and tell the experimenter what they had to do. Subjects had a clock to monitor time. Once again, subjects had all the time they needed to navigate through this city. A total of two points were given for a correct recall of intention; one point for a correct recall of ProCom (i.e. subjects stopped the car at the appropriate time) and one point for a correct recall of RetCom (i.e. subjects told the experimenter the correct action associated with the ProCom). For TBPM, the ProCom point was given for answers for which deviation to the time-point did not exceed 10 seconds. As a result, each condition was scored on six points, and the overall PM score was on 18 points. At the end of the immersion, subjects were asked to judge retrospectively their performance on the task on a five-point Likert scale (from 1: not at all, to 5: perfectly).
- *Post-test recall.* At the end of the experiment, subjects were asked to recall the nine intentions in a free and a cued-recall test.

The total experiment lasted about 45 minutes.

2.4 Neuropsychological Assessment

To better understand processes underlying PM, using this VR device, we assessed other cognitive functions with classical neuropsychological tests. Retrospective episodic memory was assessed using the free and cued recall of a list of 16 items, immediately as well as after a delay of 20 minutes. Concerning executive functions (Miyake, Friedman, Emerson, Witzki & Howerter, 2000), we assessed shifting (execution time in seconds of the Trail Making Test, part B), inhibition (reading time in seconds of the interference part of the Stroop) and updating (number of correct trials of the running span) functions. Other cognitive functions that are supposed to play a role in PM were assessed, namely dual task (percentage of cost in dual condition of the dual-task paradigm of Baddeley), planning (sequencing score of the Zoo Map Test), time estimation (percentage of deviation relative to real durations) and binding processes (number of correct answers in a multi-modal integration task, see Quinette, Guillery-Girard, Noël, de La Sayette, Viader, Desgranges & Eustache, 2006). Finally, a metamemory questionnaire (PRMQ, Smith et al, 2000) was proposed to subjects to evaluate their subjective memory complaints.

3. RESULTS

3.1 *Effect of Nature of the Task on PM Performance*

As a whole, subjects performed quite well on the PM tasks. Due to the restricted number of items by condition (i.e. three), non parametric analyses (Wilcoxon tests) were conducted on correct PM answers to assess Nature (Link-EBPM vs noLink-EBPM vs TBPM) and Component (ProCom vs RetCom) of PM effects (see Figure 3).

Consistently with our predictions, analyses revealed that the recall was higher in the Link-EBPM condition compared to noLink-EBPM ($Z = 2.69$; $p < 0.01$) and TBPM ones ($Z = 2.81$; $p < 0.01$), which did not differ significantly from each other ($Z = 0.55$; $p = 0.57$). ProCom tended to be better recalled than RetCom ($Z = 1.78$, $p = 0.07$). Finally, the better recall for Link-EBPM condition compared to noLink-EBPM and TBPM, which did not differ, was restricted to the recall of RetCom ($Z = 2.66$, $p < 0.01$; $Z = 2.73$, $p < 0.01$ and $Z = 0.22$, $p = 0.82$; respectively). Parametric analyses (ANOVA and Tukeys' HSD post-hoc) demonstrated quite similar pattern of results.

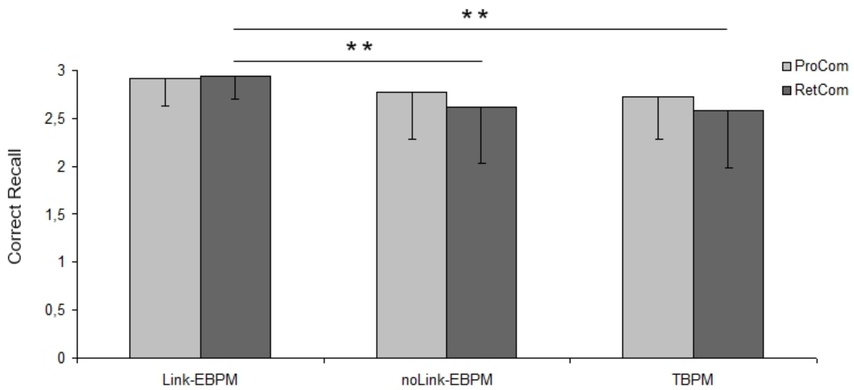

Figure 3: *Correct recall of Prospective (ProCom) and Retrospective (RetCom) Components during Prospective Memory evaluation according to the nature of intentions (Link-EBPM vs noLink-EBPM vs TBPm). ** p < 0.01.*

Table 1. *Correlations between PM scores and the other cognitive functions.*

		Link-EBPM	noLink-EBPM	TBPM
Recall of 16 words	Immediate	-0,11	0,36*	0,23
	Delayed	0,02	0,56***	0,26
Executive functions	Shifting	-0,09	0,13	-0,40*
	Updating	-0,10	0,06	0,35*
	Inhibition	-0,22	0,10	-0,16
Working Memory	Dual Task	-0,15	-0,21	-0,12
	Binding	0,35*	0,27	0,23
Planning		-0,06	0,25	0,01
Time estimation		-0,17	0,05	0,05
Metamemory	Reports of Memory failures	-0,08	0,03	-0,06
	Prediction on PM-VR task	0,37*	0,06	0,10
	Postdiction on PM-VR task	0,29	0,25	0,59***

Note : * $p<0.05$; ** $p< 0.01$, *** $p<0.001$

3.2 Link between PM and Cognitive Functions

After this first step, we conducted correlations analyses to identify processes subtending PM according to the nature of the task. Spearman correlations were assessed between PM scores (Link-EBPM, noLinkEBPM and TBPM) and scores obtained on neuropsychological evaluation (retrospective episodic memory, executive functions, working memory, planning, time estimation and metamemory), as well as subjects prediction and post-diction of their performance during the task. They showed distinct cognitive correlates for PM according to the condition (Table 1). Link-EBPM was correlated with binding processes, as well as subjects' prediction of their performance. NoLink-EBPM was correlated with immediate and delayed recall in retrospective episodic memory. Finally, TBPM was correlated with executive function, notably shifting and updating, as well as with subjects' postdiction of their performance.

4. DISCUSSION

The present study aimed to evaluate PM using a realistic device, which nonetheless allowed us to strictly control experimental conditions. More specifically we wanted to assess the impact of the link between ProCom and RetCom on the distinction between EBPM and TBPM situations. Consistently with our predictions, we found that Link-EBPM elicited better performance than noLink-EBPM and TBPM, which did not differ from each other. In fact, this effect was found only for the retrieval of RetCom. In other words, it is harder to retrieve the intended action when the link between the ProCom and the RetCom is weak than when it is strong. Those results are consistent with the reflexive-associative theory of PM (McDaniel et al. 2004) which suggests that the mere detection of the cue is sufficient to allow reflexive and automatic recollection of the intended action if the association between the two components is strong enough. As a result, implication of binding processes may be critical for successful PM, as it has already been demonstrated (Gonneaud et al., 2011). Consistently, we found that Link-EBPM was correlated with binding processes.

When associative processes are not efficient, the detection of the event or the moment to act might not be sufficient to trigger retrieval of the intended action, leading to PM failure. Under such conditions, implication of additional processes would be required. This was the case in our study where, when the link was not obvious between ProCom and RetCom (i.e. noLink-EBPM and TBPM conditions), subjects relied on different processes to succeed. Nevertheless, while performance on PM tasks suggests that the limited link between ProCom and RetCom could cause equivalent difficulties in noLink-EBPM and TBPM conditions, processes involved in those two conditions are distinct. In fact, while no-Link EBPM was associated with retrospective episodic memory performance, TBPM was associated with executive functions performance. The correlations between noLink-EBPM and retrospective episodic memory suggest that, when detection of the target cannot elicit spontaneous retrieval of the action associated, active search in memory is required, similarly as during the recovery of past events. In contrast, correlations between TBPM and executive functions, namely shifting and updating functions (see also Kliegel, Ramuschkat & Martin, 2003), fit with the idea that TBPM requires much more self-initiated processes than EBPM in order to shift attention from ongoing task to time monitoring. Moreover, correlation with updating may reflect the involvement of this function in the re-evaluation of durations while the time elapses. Thus, the lack of links between ProCom and RetCom makes the execution of delayed intention harder, but cannot fully explain the complexity of TBPM.

Contrary to our predictions, no correlation was found between PM and planning function, time estimation, inhibition or dual task processes, neither with self-reports of memory failures in daily-life. A lack of variability in young healthy subjects could in part account for this result.

Overall this study brings new data about assessment and potential rehabilitation of PM disorders. First, it demonstrates that VR is a sensitive tool that can be used to assess theoretical questions about cognitive functions as PM, even in healthy young population. To go further in our understanding of PM, the same procedure should be used in population showing impaired PM. In fact, such evaluation could allow a better understanding and characterisation of healthy older people and patients with PM deficits. By offering the same procedure to patients, it might be easier to highlight the involvement of planning, time estimation, inhibition or dual task processes in PM impairment (Trawley, Law & Logie, 2011). More particularly, we suggest that VR could provide a better assessment of their daily-life memory impairments than the classical laboratory evaluation.

Finally, our findings highlight that the strength of association between the ProCom and the RetCom is critical in PM success. As a result, rehabilitation programs for patients could focus on reinforcement of the link between these two components of PM. Consistently, previous studies showed that implementation intention (i.e. verbal commitment pairing the future context and the intended action: "if X occurs, then I will

do Y") and imagery (i.e. instruction to imagine oneself performing the intended action) can improve PM performance (McFarland & Glisky, 2012). The use of such technique in a VR device, like the one we used in this study, could be very suitable for the rehabilitation of PM deficits to help patients to 1) develop such strategies and 2) generalise their use in their daily living.

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Measuring the effect of affective stimuli on autonomic responses and task performance in a virtual environment by children with and without cerebral palsy

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ABSTRACT

This study examined whether a functional virtual environment (VE) may be used to provide affective stimuli (AS) that lead to changes in the emotional responses and task performance of children with and without cerebral palsy (CP). Fifteen children with CP and 19 typically developing (TD) peers (6 to 12 years) prepared seven virtual meals in a predefined order within a virtual meal-making VE, referred to as the Emotional Meal-Maker (EMM), run on a 2D video capture VR platform. During each of six meals either a negative, positive, or neutral visual stimulus, selected from the International Affective Picture System (IAPS), was displayed. Heart rate (HR) and skin conductance (SCR) were recorded online in synchrony with stimulus onset. These variables were also recorded when the children passively viewed the same sequence of affective pictures displayed onscreen while rating their valence and arousal levels. Autonomic responses were calculated as the amount of change in the autonomic variables compared to baseline. Correlations between behavioural characteristics (i.e., trait and state anxiety) with both autonomic responses and task performance were also calculated. Significant differences were found between groups in task performance and heart rate variability (HRV) components, i.e., a higher “low frequency” (LF) to “high frequency” (HF) ratio in the children with CP during the meals in which a negative stimulus was displayed ($U= 59.00$, $p= 0.011$) and during the passive visual display, regardless of type of stimulus. For children with CP, the amplitude of skin conductance response during the passive pictures display was significantly higher for negative stimuli (0.80 ± 0.46 µS) than for positive stimuli (0.52 ± 0.28; $Z= -2.38$, $p= 0.017$), but there were no significant changes in autonomic responses as a function of stimuli during meal-making. Positive correlations were found in the CP group between trait anxiety and the LF:HF ratio during virtual meal-making with positive ($p< 0.05$) and negative stimuli ($p<0.01$) but not during meals when stimuli were neutral. The implications of these results are discussed.

1. INTRODUCTION

Children with a diagnosis of Cerebral Palsy (CP) have sustained primary impairments in the neuromuscular system that are activity limiting. The motor disorders are usually accompanied by disturbances of other systems such as sensation, perception, cognition, and behaviour (Rosenbaum et al., 2007). Psychological problems such as anxiety, feelings of helplessness, low self esteem, social problems and dependency have been reported in 25% to 60% of children with CP (Cohen, 2008; Krakovsky et al., 2007; Sigurdardottir et al., 2010). Overall, these problems were found to be significant barriers to participation in many activity domains (Engel Yeger et al., 2009; Imms, 2008; Majnemer et al., 2008; Parkes et al., 2010), as well as in social life and communication (Voorman et al., 2006).

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The influence of affective stimuli (AS) on task performance and children's participation is currently unknown, although there is evidence to suggest that the effect may be substantial at many levels (Mihaylov et al., 2004; Shapiro et al., 2009). The literature emphasizes that visual, auditory and olfactory stimuli can capture and divert attention regardless of their relevance to ongoing tasks (Dolcos and McCarthy, 2006). Helton and Russell (2011) further demonstrated that negative emotional stimuli that are unrelated to a task on attention-disrupted target detection even when the affective stimuli and the targets were not displayed concurrently. Several studies have demonstrated significant differences in emotional responses to stimuli between typically developing children and children with developmental delays and/or behavioural problems (e.g., Boakes et al., 2008; Conrad et al., 2007; Dawson et al., 2004; Mueller et al., 2012). For example, Shapiro et al. (2009) examined the effect of two different dental environments on the arousal level as measured by electrodermal activity in children with and without developmental disabilities. They found that a sensory adaptive environment that included special lighting effects, relaxing music, vibration, and aromas versus a conventional environment had a significantly greater calming effect on children in both groups with the decrease being most pronounced in the children with developmental delays.

Over the past decade, virtual reality technology (VR) has evolved into an evaluation and intervention tool for children with special needs (Laufer and Weiss, 2011; Parsons et al., 2009; Sandlund et al., 2011). Gesturetek's IREX video capture VR system has been shown to provide enjoyable leisure activity for young adults with cerebral palsy and severe intellectual disabilities (Weiss et al., 2003) and appears to lead to increased self-esteem, motivation (Harris and Reid, 2005) and sense of mastery in children with CP (Reid, 2002a). Studies further indicate the effectiveness of VR in promoting motor control (Bryanton et al., 2006), upper extremity functioning (Reid, 2002b) and cortical reorganization (You et al, 2005). Video capture VR may be programmed to present sensory stimuli (e.g., visual images, sounds) that accompany virtual games and functional virtual environments (VEs), providing a controlled environment for the measure of emotional aspects of children during a functional task performance.

The objectives of the study were two folded: 1) to determine whether a functional virtual environment may be used to provide affective stimuli that lead to changes in the emotional responses and in task performance outcomes of children with CP, and 2) to examine differences in emotional responses and task performance between children with CP and typically developing peers.

2. METHODS

2.1 Subjects

Fifteen children with spastic CP (study group, mean ± SD = 9.3 ± 1.4 years, 7 boys, 8 girls) and 19 typically developing (TD) children (control group, mean ± SD = 8.9 ± 1.6 years, 9 boys, 10 girls) participated in the study. Children with CP were included if they had Gross Motor Function Classification System (GMFCS) (Palisano, et al., 1997) score's range 1 to 4, had intact or corrected vision and hearing, were able to reach with their dominant hand, were able to follow multi-step instructions, and were medically stable. Ethical approval was granted by the Institutional Review Boards of the University of Haifa, the Bnai Zion Medical Center, and the Israeli Ministry of Education.

2.2 Virtual Reality Apparatus: the Emotional Meal-Maker

The Emotional Meal-Maker (EMM) VE is a modified version of the Meal-Maker, a virtual kitchen environment developed within the IREX video-capture VR system (gesturetekhealth.com) (Kirshner et al., 2011). Children were instructed to prepare as many repetitions as possible of seven different meals in a predefined order. Each meal included five relevant items for meal preparation and two non-meal distracter items, all located on virtual kitchen shelves. A 2D video camera recorded the child's gestures which thereby controlled navigation and selection of items. Only movements made by the dominant hand which was holding a red cone were captured. Selection of the virtual meal items was accomplished by dwelling over the item for 2 s. Selected items were transferred to a virtual table. Once all correct items were selected, the child hovered over a virtual "finish" button and a visual feedback on success or failure was provided.

Six different pictures from the International Affective Picture System (IAPS) (Lang et al., 2005) were selected to evoke different emotional responses in the children. Except for the first meal (hot chocolate) which was considered as a baseline meal without any AS, each of the remaining six meals presented a different stimulus with the sequence of the AS being randomized across subjects. Pictures were selected based on their valence ratings (Lang, et al., 2005). All the selected stimuli were of adult male faces. The exclusion of other affective picture types was made in order to limit possible interferences by other content, such as in animals and scenes. The onset of stimuli within each virtual meal was programmed to occur after

the child had selected the second meal item and before selecting the third item. The duration of each stimulus was set to 4 s.

2.3 Autonomic Recording and Data Reduction

Electrocardiogram (ECG) and skin conductance level (SCL) were monitored to record changes in autonomic responses via the Biopac System (www.biopac.com). These measures were selected since they represent a relatively non-obtrusive way to monitor autonomic functioning and appear to reflect emotional responses that result from affective stimuli (McManis et al., 2001). The EMM and Biopac systems were synchronized using a voice-recognition marker.

ECG Biopac EL 501 electrodes were placed over the lateral aspect of the left and right intercostal space between either the eighth and ninth ribs or ninth and tenth ribs, in a straight line below the axila. This placement was selected to maintain uniform skin contact without disturbance by upper arm and trunk movement. The ground electrode was initially placed about 10 mm above the medial malleolus of the left leg, however due to spasticity related movement of the legs observed in children with CP during the EMM, the ground electrode was placed about 2 cm to the left of the L3-L4 spiny processes.

The data were sampled at 1000 Hz and stored on a computer running Acqnowledge 3.9.1 MP100 data acquisition software. The ECG signal gain was set at 1000. The low pass (LP) filter for ECG was initially set to 35 Hz and the high pass (HP) filter was set to 0.5 Hz, with a further 2 Hz HP filter applied post acquisition.

The time between successive R waves (RR interval) was identified via the MP100 and manually checked and verified. Time domain analysis (NN50, pNN50, square toot of the mean squared differences of successive NN (RMSSD)), representing parasympathetic activity, as well as frequency domain analyses (absolute and normalized powers' values of low frequency (LF) and high frequency (HF), LF:HF ratio), indicating of sympathovagal regulation, were analyzed off-line to measure the change in heart rate variability (HRV) via Kubios HRV software version 2 (www.kubios.uku.fi).

Tonic SCL was recorded via a Biopack TSD203 SCL transducer filled with isotonic electrogel placed over the volar surface of the middle phalanges of the second and third finger of the non-dominant hand. Log transformation was carried out to normalize the distribution. The tonic SCL signal was recorded with the high pass filter set to off (DC mode); the low pass filter (LP) was set at 3 Hz post acquisition. The amplification was set to 5µSiemens/volt. AC-coupled skin conductance fluctuations were analyzed offline using AcqKnowledge 4.1 software by Biopac systems Inc. The phasic signal was derived from the tonic SCL using a smoothing baseline removal method. Amplitude of skin conductance response (SCR), measured in µSiemens (µS), was set to be the largest change relative to baseline within 1 to 6 s after stimulus onset. SCRs were included in the analysis only if the amplitude was at least 0.01 µSiemens. The square roots (SQRT) of all SCR responses were calculated in order to reduce the skewness of the distribution (Hempel et al., 2007).

Autonomic responses were calculated as the amount of change in the autonomic variables compared to baseline. For the EMM task, the baseline was considered to be the magnitude of the response that occurred during the hot chocolate meal, and for the passive visual slide display task, the baseline was considered to be the magnitude of the response that occurred during the calm state. A positive or a negative result denoted either an increase or decrease in a specific autonomic variable compared to baseline. Mean scores for autonomic responses of the same content (negative, positive, neutral) were then calculated.

2.4 Procedure

After signing informed consent, the children and their parents completed behavioural questionnaires (state and trait anxiety (STAI-S, Spielberger, 1973) and were introduced to the VR system by playing the Meal-Maker followed by a short break. ECG and SCL were monitored during three conditions: calm-state (2 minutes steady state while children sat with eyes closed listened to calm statements), while using the EMM, and during the passive visual slide display. In the latter task, the participants were required to view the AS and rate their valence and arousal using the Self-Assessment Manikin (SAM), a non-verbal pictorial rating scale (Bradley and Lang, 1994). The flow of the study protocol is presented in Fig. 1.

Based on recommendations by the Heart Rate Variability (HRV) task-force (Task force of the European Society of Cardiology and the North American Society of Pacing and Electrophysiology, 1996) the onset of the EMM marker was followed by a 2 min sampling period in order to collect sufficient HRV data for analysis. The children's cooperation during this period was encouraged by instructing them to prepare as many repetitions of each meal as they could within the 2 min period. As in the EMM, the time-interval

between each AS presented within the passive visual slide display was 2 min, and was accompanied by narrated stories from the "Grimm Brothers" tales in the same order and similar intonation for all children.

Following completion of both the MM and EMM VR tasks, subjective responses were recorded via the Short Feedback Questionnaire, child version (SFQ-Child). Online performance measures recorded during the EMM included number of correct and incorrect repetitions for each meal, total meal preparation time, and percent success (total number of correct repetitions divided by the total number of meals).

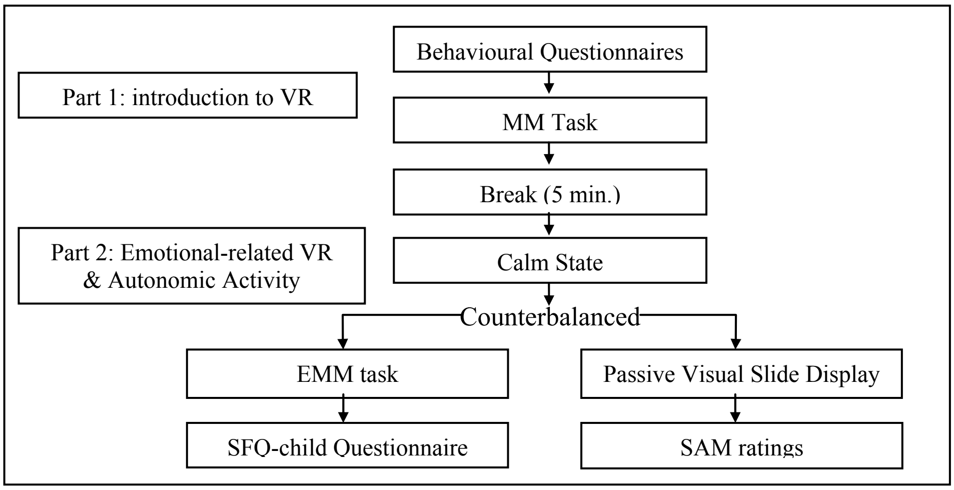

Figure 1: *Overview of study protocol.*

2.5 Statistical Analysis

The Statistical Packages for the Social Sciences (SPSS) version 15 was used for statistical analysis. A mixed design MANOVA (between subjects: CP versus typically developing children; within subjects: emotional subjective and autonomic response and task performance) with repeated measures was conducted to evaluate the differences in emotional responses and task performance while preparing a virtual meal with or without the presence of affective stimuli. Due to non-normal distributions of many of the autonomic and performance variables non-parametric tests were also used to examine differences in autonomic responses and task performance as a function of AS type within groups (Friedman test and Wilcoxon signed ranks test) and between groups (Mann-Whitney test).

Alpha was set at 0.05 but a Bonferroni correction re-defined alpha to be 0.02 for non-parametric comparisons of the three time-domain HRV components (NN50, pNN50, and RMSSD), and 0.01 for non-parametric comparisons of the five frequency-domain HRV components (absolute LF and HF values, normalized LF and HF values, and LF/HF ratio). Correlations between the behavioural questionnaires (anxiety, sensory profile) and SAM ratings with both autonomic responses and performance variables were also calculated. The Spearman correlation test was used to examine the relationships between behavioural, performance and autonomic outcomes.

3. RESULTS

3.1 Differences between Groups

In general, children with CP demonstrated different autonomic responses compared to the TD group as presented in Fig. 2. Children with CP had significantly higher heart rate and shorter RR intervals during both the calm state ($t\ (31) = -2.665$, $p = 0.012$) and during EMM activity ($t\ (31) = 2.651$, $p=0.013$) compared to TD peers. Although not significant ($\alpha > 0.01$) the normalized LF powers were higher for children with CP (56.60 ± 19.69 n.u.) than for typically developing (41.82 ± 19.69 n.u.; $U= 76.00$, $p= 0.033$) while the normalized HF values were lower for children with CP (43.40 ± 19.69 n.u.) than for typically developing (58.18 ± 20.19 n.u.; $U= 76.00$, $p= 0.033$). The LF:HF ratio of the CP group (2.15 ± 2.66) was higher than that of the TD group (0.98 ± 0.88; $U= 76.00$, $p= 0.033$).

Furthermore, while for children with CP no significant differences in autonomic activity were found when moving from calm state (hot chocolate meal) to an active EMM task for the control group, the SCL during hot chocolate preparation (0.95 ± 0.19 µS) was significantly higher than for the calm state (0.90 ± 0.16 µS; $t\ (18) = -3.513$, $p= 0.002$).

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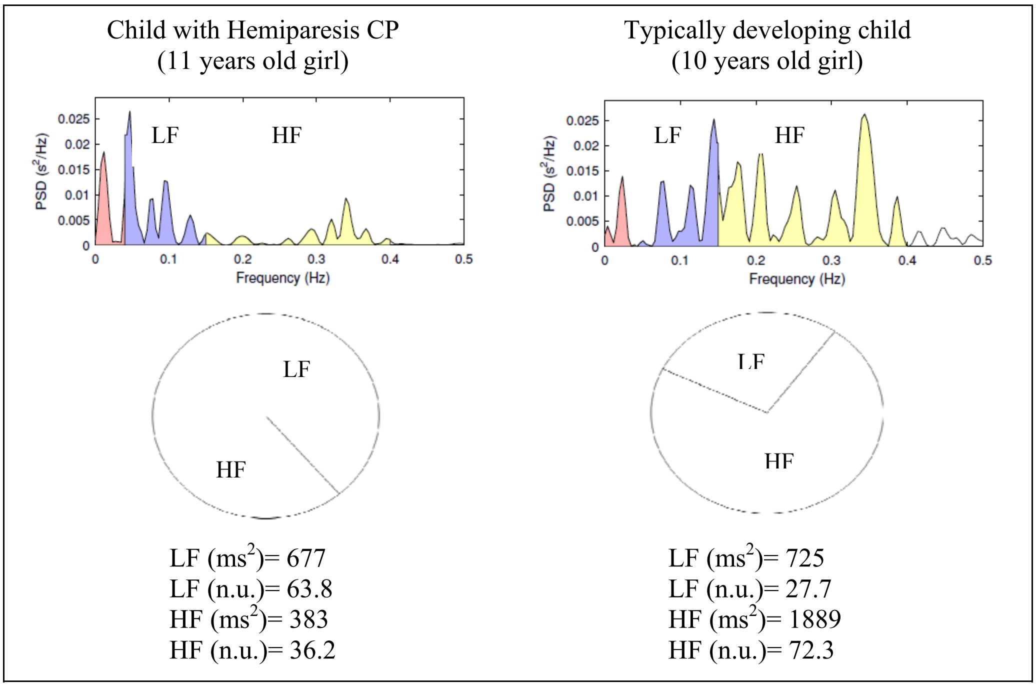

Figure 2: *Spectral analysis of HRV of two subjects during calm state, one with CP and one typically developing child. The FFT spectrum (Welch's periodogram), which indicates the presence of two major components (LF= low frequency; HF= high frequency) is illustrated in the top panels. In this example, the LF component of the child with CP is markedly dominant during calm state as compared to the typically developing child. The pie charts illustrate the distribution of LF and HF components. The graph format was adapted from [Montano et al., 2009].*

For the EMM task, HRV as represented via the LF:HF ratio response, increased significantly for children with CP (1.35 ± 1.40) relative to the typically developing children (-0.14 ± 1.28) only during the negative-related meals (U= 59.00, p= 0.011), as illustrated in Fig. 3. Greater increases in HRV via LF:HF responses were further demonstrated for the CP group than for their typically developing peers during passive visual slide display task (negative: U= 74.0, p= 0.027; neutral: U= 79.5, p= 0.045; positive: U= 63, p= 0.009).

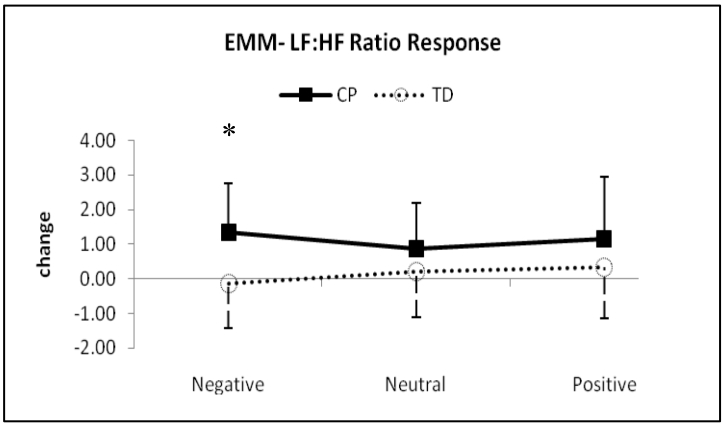

Figure 3: *HRV differences between the CP group (black line) and the typically developing group (dotted line) as a function of affective stimuli type in the EMM task (*p<0.05)*

The Mann-Whitney test found significant differences between children with CP (left panel) versus a typically developing peer (right panel) in several variables: the overall number of meals' repetitions was significantly higher for typically developing children (28.89 ± 2.21) than for children with CP (23.00 ± 4.33, U= 17.0, p= 0.000), and the overall number of correct repetitions was also significantly greater for the control group (24.79 ± 3.57) than for the CP group (17.93 ± 5.11; U= 37.0, p= 0.000). Furthermore, children with CP were

in general significantly slower (165.34 sec.± 9.68) compared to typically developing children (156.67 sec. ± 8.01; U= 64.0, p= 0.012) and they invested significantly more time preparing incorrect meals' (37.08 sec. ± 23.65) compared to the control group (21.32 sec. ± 15.0, U= 74.0, p= 0.032). The overall EMM performance success was significantly lower for children with CP (76.94% ± 13.41) than for typically developing children (85.76% ± 9.99; U= 77.0, p= 0.041).

3.2 Differences in Autonomic Responses and Task Performance as a Function of Affective Stimuli

Children with CP rated positive pictures as significantly more pleasant compared to both negative and neutral pictures (p≤ 0.05) and negative pictures were rated as significantly more arousing and less pleasant than both positive and neutral pictures (p< 0.05, p< 0.001, respectively) in the control group. Overall, the valence ratings of both positive and negative pictures, but not of neutral pictures, were significantly higher in the CP group compared to the control group (U= 79.5, p= 0.027; (U= 84.00, p=0.041, respectively). Arousal ratings did not significantly differ between groups.

Within the CP group, SCR amplitude during the passive visual slide display task was significantly higher for negative pictures (0.80 ± 0.46 μS) than for positive pictures (0.52 ± 0.28 μS; Z= -2.38, p= 0.017). However, despite the significant differences reported in the subjective ratings between AS types, children with CP did not have any significant differences in either autonomic responses or performance outcomes as a function of AS type within the EMM task).

Within the control group, the Friedman test showed significant differences in some of the time-domain HRV components (NN50, pNN50) as a function of AS type (negative, neutral, positive) during both the passive visual slide display task (NN50, Chi Square= 9.768, p= 0.008; pNN50, Chi-Square = 11.444, p= 0.003) and the EMM task (NN50, Chi Square= 12.028, p=0.002; pNN50, Chi-Square= 10.11, p=0.006). More specifically, during the passive visual slide display task there were significantly greater decreases in NN50 responses and pNN50 responses for neutral pictures than for positive pictures (NN50, Z= -2.795, p= 0.005; pNN50, Z= -2.678, p= 0.007), and during the EMM task the decrease in NN50 values compared to the baseline meal was significantly greater for neutral-related meals (-9.58 ± 13.76) than for negative-related meals (-3.53 ± 10.75; Z= -2.289, p= 0.022), suggesting that parasympathetic activity was significantly reduced during neutral-related compared to negative-related meals. As in the CP group, typically developing children did not show significant differences in EMM performance outcomes as a function of AS type.

3.3 Correlations with Behavioural Characteristics

Positive correlations were found in the CP group between trait anxiety and LF:HF ratio responses in virtual meals with positive (p< 0.05) and negative stimuli (p<0.01) but not during meals when AS were neutral. For the control group there were significant correlations between trait anxiety and both RR interval response (Rs= 0.585, p= 0.014) and heart rate response (Rs= -0.576, p= 0.012) during negative-related meals in the EMM task, indicating that during negative related meals, the more anxious typically developing children were the greater the increase in RR interval compared to baseline and the greater the decrease in heart rate compared to baseline, and vice versa.

There were no significant differences in trait and state anxiety between the groups (t (32) = -0.12, p= 0.905; t (32)= 0.82, p= 0.418, respectively).

4. DISCUSSION

This study examined whether video capture VR can be used as a platform to measure emotional aspects of function, and to what extent the autonomic responses and related performance of children with CP differ from that of typically developing peers. There were significant differences in task performance between groups in that the children with CP performed the EMM task significantly more slowly than their TD peers, prepared fewer correct meals and fewer total meals, supporting our previous work (Kirshner et al., 2011). With regard to autonomic activity, significant differences were recorded in autonomic activity between children with CP compared to typically developing peers at rest and during activity, e.g., higher heart rate for children with CP during rest and AS conditions, and higher heart rate variability as measured via LF:HF response during passive visual slide display task and during negative-related meals' preparation in the EMM task. The present study further found that when task's demands changed, for example, when children shifted from the calm state to active engagement in the virtual meal preparation task, there were significant autonomic adaptations within the typically developing children but not for the CP group.

These results are supported by the study of Park, et al. (2002) who found significant differences in frequency domain HRV components during 3 minutes of supine position and 3 minutes of head-up tilt

position between twelve children with CP aged 6 to 11 years compared to twelve typically developing children. During the supine position children with CP had a significantly greater LF: HF ratio compared to the control group, indicating greater sympathetic autonomic predominance in HR than healthy controls. Furthermore, the absolute and normalized LF powers as well as the LF:HF ratio during typically developing children's head-up tilt position were significantly increased compared to supine while the absolute HF power was significantly reduced compared to supine. These changes were not observed in the CP group. Similar results were reported by other studies who examined changes in autonomic activity between children with and without CP during supine and either head-up tilt (Yang et al., 2002) or standing (Zamuner, et al., 2011) positions. The researchers suggested that observed disturbances in cardiac autonomic regulation in children with CP are the result of loss of hemispherical influences on autonomic modulation occurring from the brain lesion itself, which may result in less adaptive reserves of the autonomic cardiac regulation (Yang et al, 2002; Zamunr, 2011). Zamuner et al. (2011) further suggested that children with CP have greater energy expenditure due to muscular tone alterations, involuntary movements, and inefficient use of muscles during compensatory muscle activity, which may account for the observed sympathetic predominance.

The processing of emotional information is considered to be prioritized relative to other incoming data (Pessoa, 2005), and hypothesized to be related to individual survival mechanisms by providing adaptive responses to safe, dangerous and life-threatening events and contexts (Lang and Bradley, 2010; Porges, 2009). Changes in autonomic responses as a function of affective stimuli were observed during the passive visual slide display task, however, they differed between groups; children with CP had significant increases in intensity of skin conductance response in the presence of negative pictures compared to positive, while typically developing children had significant increases in time domain components of HRV indicating greater parasympathetic reactivity in the presence of positive pictures compared to neutral ones. Both groups rated positive pictures as significantly more pleasant compared to both negative and neutral pictures, and negative pictures were rated as significantly less pleasant compared to neutral pictures. Taken together, these outcomes match existing evidence that emotional-related pictures can evoke subjective as well as autonomic responses in children (McManis et al, 2001; Sharp, et al, 2006). This provides support for the use of the EMM as a platform for investigating the emotional responses of children.

In contrast, when children performed a task in a virtual environment, preparing virtual meals in the presence of different affective stimuli, autonomic responses did not differ between stimulus types (in the case of children with CP) nor were greater autonomic responses observed during the neutral-related meals (in the case of typically developing children). Furthermore, there were no significant differences in EMM performance outcomes as a function of affective stimuli for either group of children. These findings are partially supported by the literature, emphasizing the interplay between emotion and cognition (e.g., Dennis, 2010; O'Toole et al., 2011). O'Toole et al. (2011) examined the interplay between task-irrelevant emotional stimuli and attention under different task difficulty demands in a sample of 63 healthy adults. In the case of the easy attention task, threatening pictures facilitated orientation, however, when task difficulty increased there were no significant differences in task performance as a function of stimulus type. A recent review by Dennis (2010) of event related potentials (ERP) studies in typically developing children further indicates that emotion and cognition act in an integrative way, that is, specific emotional state and cognitive functions have a bidirectional effect on one another in several ways, and in fact, at some stage of task processing cognition and emotion equally contribute to behavioural regulation. In the current study, the EMM task was a novel task for children in both groups, and required sustained attention during a minimum period of 14 minutes in order to be able to make as many repetitions of each meal as possible. This in itself may have considerably reduced the amount of attention paid to other, non-task-relevant stimuli, resulting in less interference by affective stimuli within the environment. It may be that a more pronounced or more dominant affective stimuli would have elicited a stronger response even during a continuous task such as the EMM. The literature shows that among the factors that contribute to intensity of emotional reactivity are physical properties of stimuli (e.g., picture size or duration of stimulus exposure), experience with the presented stimulus, and individual differences (Codispoti & De Cesarei, 2007; O'Toole et al., 2011). Moreover, the use of more than one type of affective stimulus may lead to contamination of emotional effects across trials (Pel, 2011). Since the current study was exploratory, it followed the principal idea that the natural daily environment includes many types of sensory stimuli, and it therefore, more natural to present negative, positive and neutral stimuli within the virtual kitchen task. There is a need to further examine to what extent changing the timing and style of the presentation of affective stimuli within the virtual environment will facilitate interference effects on both autonomic reactivity and task performance.

Trait anxiety was found to be an important factor in the way children handle affective stimuli, suggesting that children with higher trait anxiety have more difficulty in resisting interference effects from threat-related distracters (negative facial pictures) during a cognitive control task (Ladouceur et al., 2009; Mueller et al., 2012). In the current study, trait and state anxiety did not differ between children with and without CP.

However, different correlation patterns were observed between groups in EMM meals with different AS types. Cohen, et al., (2008) examined the associations between locus of control, parenting style, and anxiety in children with CP compared to their typically developing siblings. Their findings support the present study's outcomes, demonstrating that while baseline anxiety levels did not differ between children with CP and their siblings, there were different patterns of interactions between anxiety with psychosocial factors (locus of control, parenting style) in the two groups.

5. CONCLUSIONS

Efforts to improve the participation and performance of children with CP are usually related to the adaptation of environmental conditions to meet their cognitive and motor abilities. However, the influence of affective stimuli within the environment on emotion and performance, and their ability to improve or impede the children's participation has not been investigated in any systematic way although the emerging evidence that it affects the individuals in many levels. In general, video-capture meal-making VE was shown to be a feasible platform for the investigation of the autonomic responses of children with and without CP. Furthermore, it permitted the recording of standard physiological measures (such as skin conductance response and heart rate variability) which may have been difficult to monitor and control otherwise. They were found to be valuable for the understanding of the relation between the subjective feelings of emotions and body function.

Further studies are needed to develop additional measurements of emotional responses and to refine the types of affective interference. It is further recommended to examine the contribution of the severity of the CP type to the way children recognized and responded to affective stimuli and its relationship with autonomic responses, stress, and performance.

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Stress resilience in virtual environments: training combat relevant emotional coping skills using virtual reality

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ABSTRACT

The incidence of posttraumatic stress disorder (PTSD) in returning OEF/OIF military personnel has created a significant behavioral healthcare challenge. This has served to motivate research on how to better develop and disseminate evidence-based treatments for PTSD. One emerging form of treatment for combat-related PTSD that has shown promise involves the delivery of exposure therapy using immersive Virtual Reality (VR). Initial outcomes from open clinical trials have been positive and fully randomized controlled trials are currently in progress to further investigate the efficacy of this approach. Inspired by the initial success of this research using VR to emotionally engage and successfully treat persons undergoing exposure therapy for PTSD, our group has begun developing a similar VR-based approach to deliver stress resilience training with military service members prior to their initial deployment. The STress Resilience In Virtual Environments (STRIVE) project aims to create a set of combat simulations (derived from our existing Virtual Iraq/Afghanistan PTSD exposure therapy system) that are part of a multi-episode interactive narrative experience. Users can be immersed within challenging combat contexts and interact with virtual characters within these episodes as part of an experiential learning approach for delivering psychoeducational material, stress management techniques and cognitive-behavioral emotional coping strategies believed to enhance stress resilience. The STRIVE project aims to present this approach to service members prior to deployment as part of a program designed to better prepare military personnel for the types of emotional challenges that are inherent in the combat environment. During these virtual training experiences users are monitored physiologically as part of a larger investigation into the biomarkers of the stress response. One such construct, Allostatic Load, is being directly investigated via physiological and neuro-hormonal analysis from specimen collections taken immediately before and after engagement in the STRIVE virtual experience. This paper describes the development and evaluation of the Virtual Iraq/Afghanistan Exposure Therapy system and then details its current transition into the STRIVE tool for pre-deployment stress resilience training. We hypothesize that VR stress resilience training with service members in this format will better prepare them for the emotional stress of a combat deployment and could subsequently reduce the later incidence of PTSD and other psychosocial health conditions.

1. INTRODUCTION

War is perhaps one of the most challenging situations that a human being can experience. The physical, emotional, cognitive and psychological demands of a combat environment place enormous stress on even the best-prepared military personnel. The stressful experiences that are characteristic of the OIF/OEF warfighting environments have produced significant numbers of returning SMs at risk for developing posttraumatic stress disorder (PTSD) and other psychosocial health conditions. In the first systematic study of OIF/OEF mental health problems, the results indicated that "…The percentage of study subjects whose responses met the screening criteria for major depression, generalized anxiety, or PTSD was significantly higher after duty in Iraq (15.6 to 17.1 percent) than after duty in Afghanistan (11.2 percent) or before deployment to Iraq (9.3 percent)" (p.13) (Hoge et al., 2004). Reports since that time on OIF/OEF PTSD and psychosocial disorder rates suggest even higher incidence rates (Fischer, 2012; Seal, Bertenthal, Nuber, Sen, & Marmar, 2007; Tanielian, et al., 2008). For

example, as of 2010, the Military Health System recorded 66,934 active duty patients who have been diagnosed with PTSD (Fischer, 2012) and the Rand Analysis (Tanielian, et al., 2008) estimated that at a 1.5 million deployment level, more than 300,000 active duty and discharged Veterans will suffer from the symptoms of PTSD and major depression. With total deployment numbers now having increased to over 2 million, the Rand Analysis likely underestimates the current number of service members who may require (and could benefit from) clinical attention upon the return home. These findings make a compelling case for a continued focus on developing and enhancing the availability of evidence-based treatments to address a mental health care challenge that has had a significant impact on the lives of our Service Members (SMs), Veterans and their significant others, who deserve our best efforts to provide optimal care.

At the same time there is a powerful rationale for developing methods that promote psychological fitness within the military with the same vigor that has been traditionally applied to physical fitness (Casey, 2011). Evidence of this can be seen in the funding and resources applied to the creation of stress resilience training programs such as the U.S Army's Comprehensive Soldier Fitness (CSF) program (Cornum et al., 2011). The core motive with such efforts is to provide resilience training that would serve to reduce the later incidence of PTSD and other psychological health conditions upon redeployment home (e.g., depression, suicide, substance abuse). Recent reports of CSF longitudinal outcomes over 18 months with 22,000 soldiers have produced positive outcomes (Lester et al., 2011), but this report has been criticized for its exclusive reliance on self-report data and on other methodological grounds (PBS, 2011). Regardless of those academic "battles", the post-deployment psychological health statistics are alarming and provide a compelling justification for continued efforts to better prepare SMs for the onslaught of emotional challenges that they may face during a combat deployment. This paper will detail our initial efforts to develop, implement and evaluate a virtual reality exposure therapy (VRET) system for PTSD treatment and then discuss our ongoing efforts to retool the VR system assets into a system that could be used for resilience training prior to a combat deployment. The STress Resilience In Virtual Environments (STRIVE) project builds on the Virtual Iraq/Afghanistan simulations developed for VRET, to create a series of immersive virtual interactive narrative episodes that present exemplars of the types of emotional challenges that SMs may face during a deployment. Within those digital contexts, a virtual human agent "mentor" delivers emotional coping strategies that leverage psychoeducatonal and stress reduction tactics, along with on-the-spot cognitive behavioral appraisal training designed to enhance coping skills for use when and if the SM is confronted with similar challenges during a combat deployment. The paper will conclude with a discussion of the biological markers of the stress response that we are measuring in the STRIVE project.

2. CLINICAL VIRTUAL REALITY

Concurrent with the start and progression of the OEF/OIF conflicts, a virtual revolution has taken place in the use of Virtual Reality (VR) simulation technology for clinical and training purposes. Technological advances in the areas of computation speed and power, graphics and image rendering, display systems, body tracking, interface technology, haptic devices, authoring software and artificial intelligence have supported the creation of low-cost and usable VR systems capable of running on a commodity level personal computer. VR allows for the precise presentation and control of stimuli within dynamic multi-sensory 3D computer generated environments, as well as providing advanced methods for capturing and quantifying behavioral responses. These characteristics serve as the basis for the rationale for VR applications in the clinical assessment, intervention and training domains. The unique match between VR technology assets and the needs of various clinical treatment and training approaches has been recognized by a number of scientists and clinicians, and an encouraging body of research has emerged that documents the many clinical targets where VR can add value to clinical assessment and intervention (Holden, 2005; Parsons and Rizzo, 2008; Rizzo et al., 2011a; Riva, 2011; Rose, Brooks and Rizzo, 2005). To do this, VR scientists have constructed virtual airplanes, skyscrapers, spiders, battlefields, social settings, beaches, fantasy worlds and the mundane (but highly relevant) functional environments of the schoolroom, office, home, street and supermarket. Emerging R & D is also producing artificially intelligent virtual human agents that are being used in the role of virtual patients for training clinical skills to novice clinical professionals (Lok et al., 2007; Rizzo et al., in press) and as anonymous online healthcare support agents (Rizzo et al., 2011b). This convergence of the exponential advances in underlying VR enabling technologies with a growing body of clinical research and experience has fueled the evolution of the discipline of Clinical Virtual Reality. And this state of affairs now stands to transform the vision of future clinical practice and research to address the needs of both civilian and military populations with clinical health conditions.

3. VIRTUAL IRAQ/AFGHANISTAN EXPOSURE THERAPY SYSTEM

Among the many approaches that have been used to treat persons with PTSD, graduated exposure therapy appears to have the best-documented therapeutic efficacy (Rothbaum, 2001; Bryant et al., 2005). Such treatment typically involves the graded and repeated imaginal reliving and narrative recounting of the traumatic event within the therapeutic setting. This approach is believed to provide a low-threat context where the client can begin to confront and therapeutically process the emotions that are relevant to a traumatic event as well as de-condition the learning cycle of the disorder via a habituation/extinction process. While the efficacy of imaginal exposure has been established in multiple studies with diverse trauma populations (Rothbaum, et al., 2000, 2001, 2002), many patients are unwilling or unable to effectively visualize the traumatic event. In fact, avoidance of reminders of the trauma is inherent in PTSD and is one of the cardinal symptoms of the disorder.

To address this problem, researchers have recently turned to the use of VR to deliver Exposure Therapy (VRET) by immersing users in simulations of trauma-relevant environments in which the emotional intensity of the scenes can be precisely controlled by the clinician in collaboration with the patients' wishes. In this fashion, VRET offers a way to circumvent the natural avoidance tendency by directly delivering multi-sensory and context-relevant cues that aid in the confrontation and processing of traumatic memories without demanding that the patient actively try to access his/her experience through effortful memory retrieval. Within a VR environment, the hidden world of the patient's imagination is not exclusively relied upon and VRET may also offer an appealing treatment option that is perceived with less stigma by "digital generation" SMs and Veterans who may be more reluctant to seek out what they perceive as traditional talk therapies.

These ideas have been supported by three reports in which patients with PTSD were unresponsive to previous *imaginal* exposure treatments, but went on to respond successfully to VR exposure therapy (Difede & Hoffman, 2002; Difede et al, 2006; Rothbaum, Hodges, Ready, Graap & Alarcon, 2001). As well, VR provides an objective and consistent format for documenting the sensory stimuli that the patient is exposed to that is not possible when operating within the unseen world of the patient's imagination. Based on this, the University of Southern California Institute for Creative Technologies developed a "Virtual Iraq/Afghanistan" simulation that is being used in a variety of clinical trials to investigate the efficacy of this form of treatment (see Figure 1).

Figure 1. *Virtual Iraq/Afghanistan: Middle Eastern City and Desert Road HUMVEE scenarios.*

The treatment environment consists of a series of virtual scenarios designed to represent relevant contexts for VR exposure therapy, including city and desert road environments. In addition to the visual stimuli presented in the VR head mounted display, directional 3D audio, vibrotactile and olfactory stimuli of relevance can be delivered. Stimulus presentation is controlled by the clinician via a separate "wizard of oz" interface, with the clinician in full audio contact with the patient. User-Centered tests with the application were conducted at the Naval Medical Center–San Diego and within an Army Combat Stress Control Team in Iraq. This feedback from non-diagnosed personnel provided information on the content and usability of our application that fed an iterative design process leading to the creation of the current clinical scenarios. A detailed description of the Virtual Iraq/Afghanistan system and the methodology for a standard VRET clinical protocol can be found elsewhere (Rothbaum, Difede, & Rizzo, 2008).

Initial clinical tests of the system have produced promising results. In the first open clinical trial, analyses of 20 active duty treatment completers (19 male, 1 female, Mean Age=28, Age Range: 21-51) produced

positive clinical outcomes (Rizzo et al., 2011a). For this sample, mean pre/post PCL-M (Blanchard et al., 1996) scores decreased in a statistical and clinically meaningful fashion: 54.4 (SD =9.7) to 35.6 (SD = 17.4). Paired pre/post t-test analysis showed these differences to be significant (t=5.99, df=19, p < .001). Correcting for the PCL-M no-symptom baseline of 17 indicated a greater than 50% decrease in symptoms; 16 of the 20 completers no longer met PCL-M criteria for PTSD at post treatment. Five participants in this group with PTSD diagnoses had pre-treatment baseline scores below the conservative cutoff value of 50 (pre-scores = 49, 46, 42, 36, 38) and reported decreased values at post treatment (post-scores = 23, 19, 22, 22, 24, respectively). Mean Beck Anxiety Inventory (Beck et al., 1988) scores significantly decreased 33% from 18.6 (SD = 9.5) to 11.9 (SD = 13.6), (t=3.37, df=19, p < .003) and mean PHQ-9 (Kroneke and Spitzer, 2002) (depression) scores decreased 49% from 13.3 (SD= 5.4) to 7.1 (SD = 6.7), (t=3.68, df=19, p < .002). The average number of sessions for this sample was just under 11. Results from uncontrolled open trials are difficult to generalize from and we are cautious not to make excessive claims based on these early results. However, using an accepted military-relevant diagnostic screening measure (PCL-M), 80% of the treatment completers in the initial VRET sample showed both statistically and clinically meaningful reductions in PTSD, anxiety and depression symptoms, and anecdotal evidence from patient reports suggested that they saw improvements in their everyday life. These improvements were also maintained at three-month post-treatment follow-up.

Other studies have also reported positive outcomes. Two early case studies reported positive results using this system (Gerardi et al., 2008; Reger & Gahm, 2008). Following those, another open clinical trial with active duty soldiers (n=24) produced significant pre/post reductions in PCL-M scores and a large treatment effect size (Cohen's *d* = 1.17) (Reger et al., 2011a). After an average of 7 sessions, 45% of those treated no longer screened positive for PTSD and 62% had reliably improved. Three randomized controlled trials (RCTs) are ongoing with the *Virtual Iraq/Afghanistan* system with active duty and Veteran populations. Two RCTs are focusing on comparisons of treatment efficacy between VRET and prolonged imaginal exposure (PE) (Reger & Gahm, 2010, 2011b) and VRET compared with VRET + a supplemental care approach (Beidel, Frueh & Uhde, 2010).

A third RCT (Difede, Rothbaum & Rizzo, 2010) is investigating the additive value of supplementing VRET and imaginal PE with a cognitive enhancer called D-Cycloserine (DCS). DCS, an N-methyl-d-aspartate partial agonist, has been shown to facilitate extinction learning in laboratory animals when infused bilaterally within the amygdala prior to extinction training (Walker, Ressler, Lu, and Davis, 2002). The first clinical test in humans that combined DCS with VRET was performed by Ressler et al. (2004) with participants diagnosed with acrophobia (n=28). Participants who received DCS + VRET experienced significant decreases in fear within the virtual environment 1 week and 3 months post-treatment, and reported significantly more improvement than the placebo group in their overall acrophobic symptoms at 3 month follow-up. This group also achieved lower scores on a psychophysiological measure of anxiety than the placebo group. The current multi-site PTSD RCT will test the effect of DCS vs. placebo when added to VRET and PE with active duty and veteran samples (n=300).

4. STRESS RESILIENCE IN VIRTUAL ENVIRONMENTS (STRIVE)

The current urgency in efforts to address the psychological wounds of war in SMs and Veterans has also driven an emerging focus within the military on emphasizing a proactive approach for better preparing service members for the emotional challenges they may face during a combat deployment to reduce the potential for later adverse psychological reactions such as PTSD and depression. This focus on resilience training prior to deployment represents no less than a quantum shift in military culture and can now be seen emanating from the highest levels of command in the military. For example, in an American Psychologist article, Army General George Casey (2011) makes the case that "…soldiers can "be" better before deploying to combat so they will not have to "get" better after they return." (p. 1), and he then calls for a shift in the military "…to a culture in which psychological fitness is recognized as every bit as important as physical fitness." (p. 2). This level of endorsement can be seen in practice by way of the significant funding and resources applied to a variety of stress resilience training programs across all branches of the U.S. Military (Luthar, Cicchetti & Becker, 2000; Hovar, 2010).

Resilience is the dynamic process by which individuals exhibit positive adaptation when they encounter significant adversity, trauma, tragedy, threats, or other sources of stress (McEwen & Stellar, 1993). The core aim of resilience training is to promote psychological fitness and better prepare service members for the psychological stressors that they may experience during a combat deployment. Perhaps the program that is

attempting to influence the largest number of SMs is the Comprehensive Soldier Fitness (CSF) program (Cornum, Matthews & Seligman, 2011). This project has created and disseminated training that aims to improve emotional coping skills and ultimate resilience across all Army SMs. One element of this program draws input from principles of cognitive-behavioral science, which generally advances the view that it is not the event that causes an emotion, but rather how a person appraises the event (based on how they think about the event) that leads to the emotion (Ortony, Clore & Collins, 1988). From this theoretical base, it then follows that internal thinking or appraisals about combat events can be "taught" in a way that leads to more healthy and resilient reactions to stress. This approach does not imply that people with effective coping skills do not feel some level of "rational" emotional pain when confronted with a challenging event that would normally be stressful to any individual. Instead, the aim is to teach skills that may assist soldiers in an effort to cope with traumatic stressors more successfully.

The STRIVE project has evolved from the Virtual Iraq/Afghanistan VRET system and aims to foster stress resilience by creating a set of combat simulations that can be used as contexts for SMs to experientially learn stress reduction tactics and cognitive-behavioral emotional coping strategies prior to deployment. This approach involves immersing and engaging SMs within a variety of virtual "mission" episodes where they are confronted with emotionally challenging situations that are inherent to the OEF/OIF combat environment. Interaction by SMs within such emotionally challenging scenarios aims to provide a more meaningful context in which to engage with psychoeducational information and to learn and practice stress reduction tactics and cognitive coping strategies that are believed to psychologically prepare a SM for a combat deployment. To accomplish this, STRIVE is being designed as a 30-episode interactive narrative in VR, akin to being immersed within a "Band of Brothers" type storyline that spans a typical deployment cycle. Within these episodes, SMs will get to know the distinct personalities of the virtual human characters in their squad and interact within an immersive digital narrative that employs cinematic strategies for enhancing engagement with the evolving storyline (e.g., strategic use of narration, montage shots, dynamic camera direction). At the end of each of the graded 10-minute episodes, an emotionally challenging event occurs, designed in part from feedback provided by SMs undergoing PTSD treatment (e.g., seeing/handling human remains, death/injury of a squad member, killing someone, the death/injury of a civilian child). At that point in the episode, the virtual world "freezes in place" and an intelligent virtual human "mentor" character emerges from the midst of the chaotic VR scenario to guide the user through stress-reduction psychoeducational and self-management tactics, as well as providing rational restructuring exercises for appraising and processing the virtual experience. The stress resilience training component is drawing on evidence-based content that has been endorsed as part of standard classroom-delivered DOD stress resilience training programs, as well as content that has been successfully applied in non-military contexts (e.g., humanitarian aid worker training, sports psychology).

In this fashion, STRIVE provides a digital "emotional obstacle course" that can be used as a tool for providing context-relevant learning of emotional coping strategies under very tightly controlled and scripted simulated conditions. Training in this format is hypothesized to improve generalization to real world situations via a state dependent learning component (Godden & Baddeley, 1980) and further support resilience by leveraging the learning theory process of latent inhibition. Latent inhibition refers to the delayed learning that occurs as a result of pre-exposure to a stimulus without a consequence (Feldner, Monson & Friedman, 2007; Lubow & Moore, 1959). Thus, the exposure to a simulated combat context is believed to decrease the likelihood of fear conditioning during the real event (Sones, Thorp & Raskind, 2011).

5. STRESS BIOMARKERS AND ALLOSTATIC LOAD

The STRIVE project also incorporates a novel basic science protocol. While other stress resilience efforts typically incorporate one or two biomarkers of stress and or resilience, the STRIVE projects will measure what we refer to as the "physiological fingerprint of stress," commonly called Allostatic Load (AL). The theoretical construct of AL, initially developed by one of the STRIVE collaborators, Bruce McEwen, is a measure of cumulative wear and tear on physiological symptoms due to chronic stress (McEwen & Stellar, 1993). As a theoretical construct, it is a preliminary attempt to formulate the relationship between environmental stressors and disease, by hypothesizing mechanisms whereby multiple kinds of stressors confer risk simultaneously in multiple physiological systems. The construct of AL is based on the widely accepted response called allostasis. Sterling and Eyer (1988) defined allostasis as the body's set points for various physiological mechanisms, such as blood pressure or heart rate, which vary to meet specific external demands, e.g., emotional stress. McEwen and Stellar (1993) furthered our understanding of allostasis by broadening its scope. Rather than discuss allostasis in terms of a single set point that changed in response to a

stressor, they described allostasis as the combination of all physiological coping mechanisms that are required to maintain equilibrium of the entire system. Thus, allostasis is the reaction and adaptation to stressors by multiple physiological systems that brings the system back to equilibrium. The related concept of homeostasis refers specifically to system parameters essential for survival (McEwen, 2002). To place AL into the context of allostasis, allostasis does not always proceed in a normal manner. Any of the major physiological systems (e.g., inflammatory, metabolic, immune, neuroendocrine, cardiovascular, respiratory) in the process of responding to stress can exact a cost, or an allostatic load, that can result in some form of physiological or psychological disturbance. McEwen (2000) identified four types of AL. The first is frequent activation of allostatic systems; (2) is a prolonged failure to shut off allostatic activity after stress; (3) is a lack of adaptation to stress, and (4) is an inadequate response of allostatic systems leading to elevated activity of other, normally counter-regulated allostatic systems after stress (e.g., inadequate secretion of glucocorticoid resulting in increased cytokines normally countered by glucocorticoids). Any of these types of AL intervene with the normal stress response of allostasis thus increasing AL. This will increase one's risk for disease in the long-term and may preclude the short-term development of physical hardiness and psychological resilience.

From a conceptual standpoint, the construct of AL is still undergoing development. More recent AL models posit the interaction of biomarkers on multiple levels. Juster et al., (2009) theorize that by measuring multi-systemic interactions among primary mediators (e.g., levels of cortisol, adrenalin, noradrenalin) and relevant sub-clinical biomarkers representing secondary outcomes (e.g., serum HDL and total cholesterol), one can identify individuals at high risk of tertiary outcomes (e.g., disease and mental illness). Yet we argue this approach does not fully encapsulate the dynamic, nonlinear, evolving, and adaptive nature of the interactions between these biomarkers. Moreover, these markers are not purely physiological. Psychological processes, including appraisal of and reactions to various stressors, e.g., resilience, may constitute a separate but interdependent subsystem in the allostatic model. We support a case-based approach to analysis, which acknowledges that each allostatic system is unique in its configuration based on differences in (1) environmental context, including the user's socioeconomic status and availability of psychosocial resources; (2) regulation and plasticity of bio-allostatic systems; (3) regulation and plasticity of what we term psycho-allostatic systems; (4) psychology, including personality and appraisal of stressors; (5) environmental stressors, which range from biological to sociological; and (6) health outcomes. For STRIVE, AL will be measured via the capture and integration of complex biomarkers known to indicate physiological dysfunction and normal function for numerous physiological systems (e.g., immune, cardiovascular, metabolic).

In a first study of its kind, we will determine if AL can predict acute response to stress (e.g., EEG, GSR, ECG, pupil dilation, etc.), when participants are exposed to the stressful VR missions. Further analyses will determine if AL can predict participants' responses to virtual mentor instructions on how the participants can cope with stress through stress resilience training. If we find that AL is capable of predicting either short-term response to stress or the ability to learn stress resilience, there would be numerous implications for the future use of AL, including identification of leadership profiles and for informing the development of appropriate training systems for all SMs. Pilot research on this project is ongoing at the Immersive Infantry Training center at Camp Pendleton and the status of that work will be presented at the ICDVRAT conference.

6. CONCLUSIONS

The STRIVE program is designed to both create a VR application for enhancing SM stress resilience and to provide a highly controllable laboratory test bed for investigating the stress response. Success in this area could have significant impact on military training and for the prevention of combat stress related disorders. Another option for use of the STRIVE system could involve its application as a VR tool for emotional assessment at the time of recruitment to the military. The large question with such an application involves whether it would be possible (and ethical) to assess prospective SMs in a series of challenging combat-relevant emotional environments delivered in the STRIVE system, to predict their potential risk for developing PTSD or other mental health difficulties based on their verbal, behavioral and physiological/hormonal reactions recorded during these virtual engagements. To use such information for recruitment decisions would require a change from current military thinking, where doctrine dictates that anyone can be made into an infantryman. However, practical implementation of such an approach could advise that those who display reactions that predict them to be most at risk to have a negative stress reaction post-combat, could either be assigned non-combat duties, not accepted into the services, or more preferably, presented with the opportunity to participate in a stress resilience training program that could minimize their identified risk to post-trauma dysfunction. This is not a new concept. Since the early days of the Army Alpha/Beta, assessments have been routinely conducted that are designed to predict what role is best suited to

the unique characteristics and talent of a given recruit. Moreover, potential recruits are not accepted into the military for many reasons that are more easily measurable (e.g., having a criminal record, poor physical fitness, significant health conditions).

For this effort, the pragmatic challenge would be in the conduct of prospective longitudinal validation research. This would require the initial testing of a large number of SMs within standardized virtual simulations (i.e., STRIVE), to record and measure reactions for establishing a baseline and for also determining if advanced data mining procedures could detect whether consistent patterns of responding do in fact exist. SMs in this large sample could then be closely monitored for their mental health status during and after their deployment. Once a large enough sample of SMs were identified as having stress related problems, it would be possible to go back to their physiological and behavioral data from the earlier simulation experience and analyze for a consistent reactivity pattern that could differentiate this group and then serve as a marker for predicting problems in future recruits. The challenges for conducting this type of research are also significant beyond the pragmatics of conducting costly longitudinal research. These would include the pressure that an all-volunteer service puts on the military to attract and maintain sufficient numbers, the traditional view that all recruits can be trained to success, and the potential that some future service members could be misidentified as high risk (false positives) and be denied access to joining the military. This further suggests that in addition to simply identifying the emotional and physiological profile associated with long-term stress-related dysfunction, a further step would be to tailor stress resilience training for specific emotional and physiological profiles. More extensive and in-depth stress resilience training programs could then be clearly proposed for those identified as at risk for PTSD and other psychosocial health conditions. And, the implications for research into individual susceptibility to stress related disorders could have ramifications beyond the military community. As we have seen throughout history, innovations that emerge in military healthcare, driven by the urgency of war, typically have a lasting influence on civilian healthcare long after the last shot is fired.

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Towards a real-time, configurable, and affordable system for inducing sensory conflicts in a virtual environment for post-stroke mobility rehabilitation: vision-based categorization of motion impairments

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ABSTRACT

Upper body motion impairment is a common after-effect of a stroke. A virtual reality system is under development that will augment an existing intervention (Mirror Box therapy) with a method of inducing a body illusion (Rubber Hand) in order to enhance rehabilitation outcomes. The first phase of the project involved developing algorithms to automatically differentiate between normal and impaired upper body motions. Validation experiments with seven healthy subjects simulating two common types of impaired motions confirm the effectiveness of the proposed methods in detecting impaired motions (accuracy >95%).

1. INTRODUCTION

1.1 Background

Hemiparesis, or weakness on one side of the body, is a common after-effect of a stroke. A well-known body illusion, known as the mirror box illusion, is used in rehabilitation training exercises that have been shown to be effective in restoring mobility (Altschuler et al, 1999). During the treatment, the patient enters both arms into a box with a mirror in the middle so that the view of the affected arm is replaced by the mirror reflection of the healthy arm. Simultaneous motion, or attempted motion, of both arms results in artificial visual feedback indicating that it is, in fact, the affected arm that is moving, thus promoting neurorehabilitation.

A closely related body illusion, the rubber hand illusion (Botvinick & Cohen, 1998), offers promising potential in strengthening the visual feedback from the mirror box. In this illusion, a plastic arm is placed on a table next to the real arm, which is hidden by a screen, and both the rubber hand and the real hand are simultaneously touched by a brush for a few minutes using a rhythmic motion. The temporal synchrony of the seen movements on the rubber hand and the felt movements on the real hand causes the observer to embody the rubber hand so the perceived location of the real hand is shifted towards the seen location of the rubber hand.

1.2 Objectives

The main objective of this work is to reproduce and combine the aforementioned illusions in a virtual environment. It is expected that augmenting mirror box therapy with the rubber hand illusion will strengthen the sense of ownership over the artificial visual feedback and will thus enhance the rehabilitative potential. The virtual environment will also enable a wider range of motion than a physical mirror box.

The project takes advantage of state-of-the-art computer vision and markerless skeleton tracking systems to tackle the engineering challenges and to counter some of the weaknesses identified among many of the virtual rehabilitation technologies (Rizzo & Kim, 2005), e.g. in the user interface or in the interaction methods with the virtual world. The final system is being targeted at an affordable price (≤\$200) to enable wide deployment and home usage. The system is also aimed at being easily configurable so it can be adapted to target a range of mobility impairments.

The skeleton tracking information is processed to identify impaired modes of motions by pre-processing short segments of scripted actions. This information will then be used to modify the profile of subsequent motions in real-time in order to exaggerate impaired motions, for instance by amplifying a reduced range of motion or exaggerating impaired synergies. Finally, the modified motion is displayed in a virtual environment in real-time and in synchronization with tactile feedback.

1.3 Contributions

This paper presents results from the first phase of the project, which focuses on the development of posture categorization pre-processing algorithms and preliminary validation experiments on healthy subjects. Since measuring range of motion deficits is relatively easy via skeleton tracking, the experiments presented here focus on the more challenging task of identifying motion synergies.

We have also performed preliminary experiments to validate the skeleton tracking algorithm in a specific scenario related to this research. The results identify an inherent bias in tracking the shoulder joint. We provide a short discussion on the consequences of such limitations and how they might affect the assessment of posture and motion.

2. SYSTEM DEVELOPMENT

2.1 Setup

The system employs a consumer depth sensor (a Microsoft Kinect) to capture live video and depth images and to track major skeletal joints of the body in real-time. The open source OpenNI and NITE libraries (Prime Sensor, 2010) were used to interface with the device. In the final system, touch feedback will be provided via a wearable glove, equipped with small vibrating motors, and synchronized with the visual display through a digital I/O board and a digital solid state relay board. The touch feedback interface was not utilised during the experiments reported here as it did not relate to identifying impaired motions.

2.2 Experimental Dataset

Two of the most common upper limb flexion synergies present in post-stroke patients were selected according to the Chedoke-McMaster Stroke Assessment 2005 and were simulated by healthy adults. The selected actions were (1) reaching over to the opposite shoulder via elbow flexion and shoulder flexion and adduction (cf. Fig. 1) and (2) elbow flexion (cf. Fig 2). The stereotypical post-stroke movement synergy associated with flexing the elbow is hiking the shoulder, while reaching across the body is typically accompanied by rotating the trunk (Gowland et al, 1993).

Seven healthy adults (4 males, 3 females) were recruited and asked to use their right arm to perform each of the two actions 20 times in front of the sensor, 10 times normally as they felt most comfortable and 10 times simulating the impaired motion. The 3D coordinates of the upper body skeletal positions were normalized into a subject-centred canonical coordinate frame independent of the body size and the viewing angle (Taati et al, 2012). The 3D displacement of all upper body skeletal joints in consecutive frames was computed.

2.3 Considerations of Tracking Accuracy

As the real-time skeleton tracking system used in the experiments, *i.e.* the Kinect (Shotton et al, 2011), is a relatively new technology (introduced in late 2010), its accuracy levels and limitations are not fully known and the existing literature on the topic is sparse. Most notably, Dutta (2011) evaluated the depth sensing accuracy of the device and, more recently, Clark et al. (2012) validated its skeleton tracking capabilities. When compared to a marker-based Vicon motion capture system as the ground truth, these studies concluded that the Kinect provided sub-centimetre accuracy in depth sensing in a sizable workspace (covering a range from 1 to 3 m from the sensor and a field of view of 54°) and its 3D skeleton tracking had comparable inter-trial reliability. However, Clark et al. also observed tracking biases in estimating the position of the torso and the pelvis.

During our experimentations, it was observed that the skeleton tracking library sometimes estimated joint positions that visually appeared as systematically biased in certain ways. Since the biases were mostly observed in the tracking of the elevated shoulder joint, *i.e.* different from the earlier published results reporting biases in the pelvis and the torso, a series of measurements were made to confirm and quantify this visual observation. With the growing interest in applying the Kinect and similar commercially available systems (*e.g.* ASUS WAVI Xtion) in gait assessment and other applications in rehabilitation, monitoring, and

assistive technologies, it is hoped that the results from these experiments will contribute to obtaining a better understanding of the capabilities and limitations of these technologies.

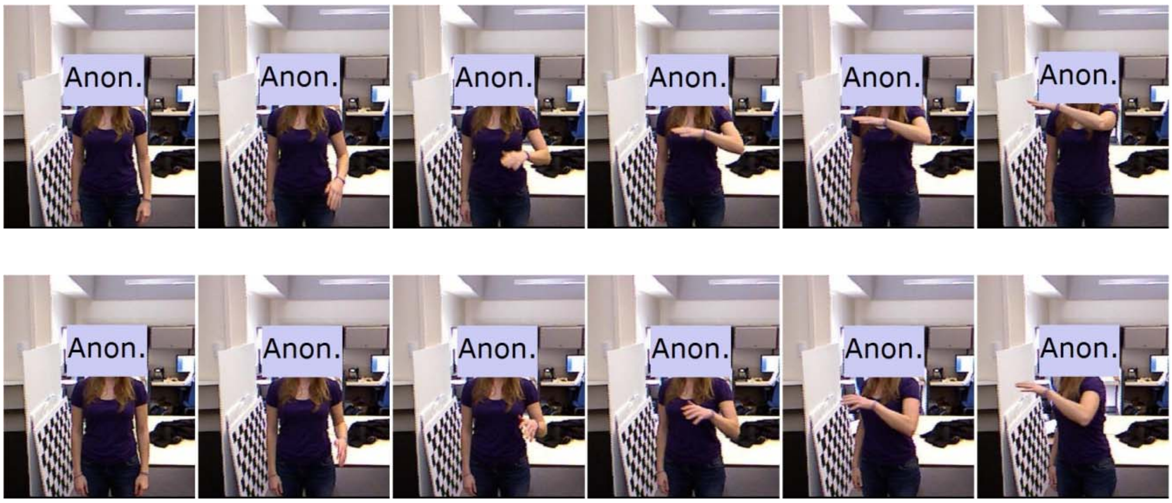

Figure 1: *Sample color, depth, and skeleton tracking images in six representative frames over two sequences of reaching across. The top row illustrate a "normal" movement pattern while the bottom row illustrate a simulated "impaired" motion synergy of rotating the trunk when reaching across, common among the post-stroke population.*

3. METHOD

3.1 *Automatic Categorization of Motion Impairments*

The system is expected to observe a human subject performing a short scripted motion, such as flexing their elbow, and to automatically analyze the motion characteristics of the upper body and detect possible impaired motions.

Principal component analysis (PCA) of the displacement vectors was used to compute the dominant modes of motion over the course of each action and the top N PCA dimensions, along with their corresponding singular values, were used as the feature set in a binary classification to distinguish between normal and simulated impaired motions. Seven-fold leave-one-subject-out cross validation was used to train and validate three binary classification algorithms, each separately trained for identifying impaired motions while flexing the elbow or while reaching across. The classification algorithms included logistic regression (LR) (Agresti, 2002), binary support vector machines (SVM) with radial basis function kernels (Joachims, 1999), and an ensemble of bagged random subsample decision trees (RT) (Breiman, 2001). The SVM and the RT are state-of-the-art machine learning algorithms (Caruana & Niculescu-Mizil, 2006) while the LR is a simple linear classifier used here as a baseline.

3.2 *Assessing the Skeleton Tracking in Impaired Motions*

With an elevated shoulder, it was visually observed that the 3D skeleton tracking repeatedly underestimated the degree by which the shoulder was elevated by a large margin (cf. Fig. 2). To confirm this observation, in seven videos simulating a motion with a hiked shoulder (one of each subject), ten frames were randomly selected for manual annotation. Two human annotators were separately asked to each mark the location of the left and the right shoulder of the subject at each frame via a mouse click and the elevation angle of the connecting lines, *i.e.* the angle with the horizontal axis in the 2D image plane, was computed.

For comparison, the same angle with the horizontal axis was also computed based on the 3D tracking data. To calculate the angle, the 3D line segment connecting the estimated location of the left and right shoulder joints, tracked in the depth sensor coordinate frame, was first transformed into the color camera coordinates via the default color-depth rigid registration of the Kinect. The 3D line was then projected onto the image plane based on the default extrinsic and intrinsic calibration parameters of color camera.

Ideally, (*i.e.* in the absence of any inaccuracies or biases in the tracking of the shoulder joints, angles computed from the skeleton) tracking data would be very close to those from the manual annotations. If the error in 3D tracking is larger than that of the 2D annotations, it is still expected that the angles be without a

bias. That is, while the variance of the angles computed from the 3D tracking could be larger, their mean will ideally be the same as that of the manual annotations.

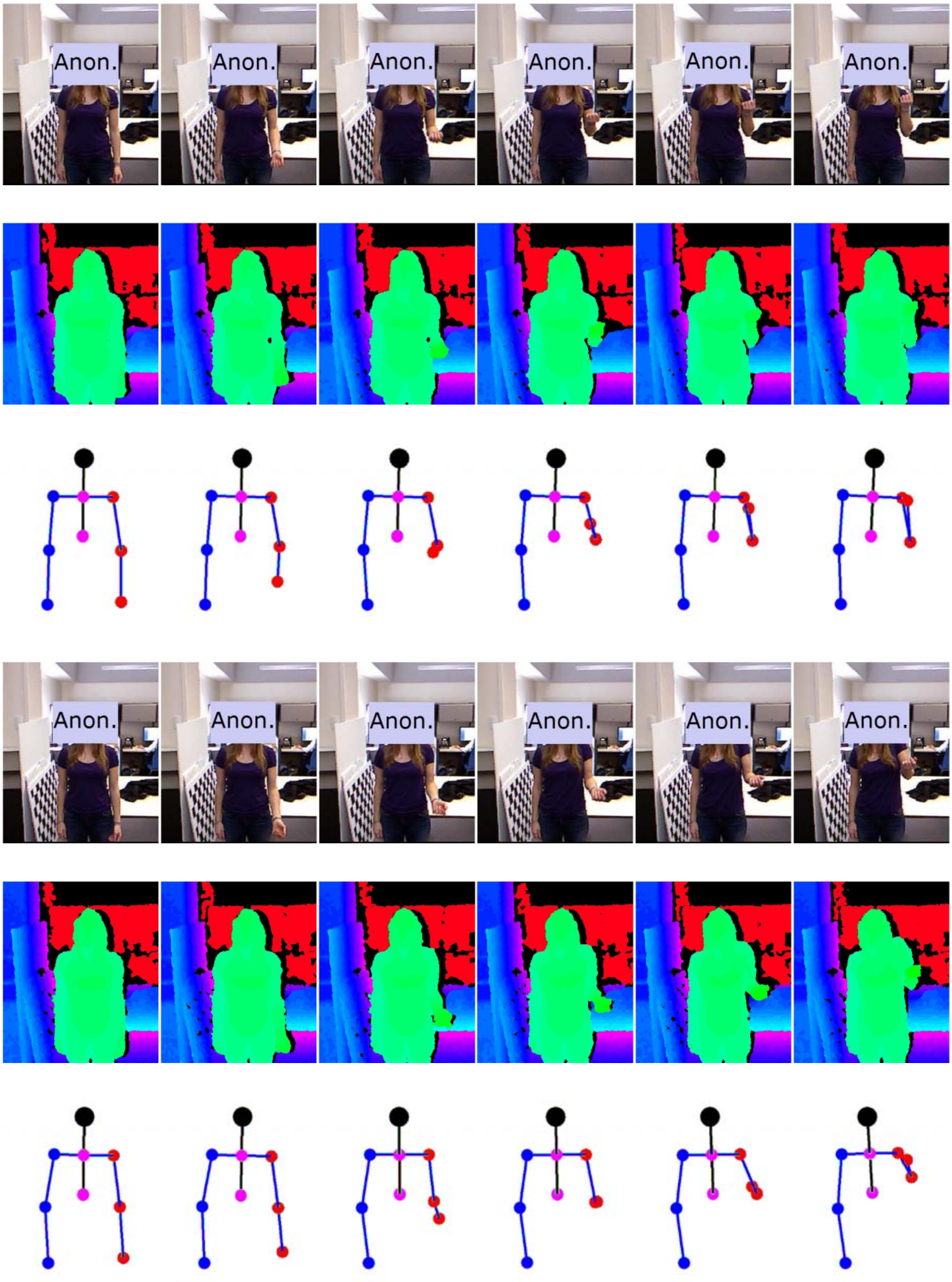

Figure 2: *Sample color, depth, and skeleton tracking images in six representative frames over two sequences of elbow flexion. The top three rows illustrate a "normal" movement pattern while the bottom three rows illustrate a simulated "impaired" motion synergy of hiking the shoulder when flexing the elbow, common among the post-stroke population.*

Admittedly, identifying the shoulder joints visually and via user mouse clicks is not always very accurate. Nevertheless, it is reasonable to assume that the human annotators will mark the left and the right shoulder similarly and their annotations will lead to an unbiased estimate of the elevation angle over the 70 frames. Furthermore, the agreement between the two manual annotators was used as a baseline to confirm the validity of the annotations. Various statistical comparisons between the angles from human annotations and the 3D tracking were used to assess the bias in the 3D tracking of elevated shoulder joints.

4. RESULTS

4.1 *Identifying Motion Impairments*

The SVM correctly identified simulated impaired motions with high accuracy (~ 96% and 97%) (cf. Table 1). The RT also provided good, albeit slightly less consistent results (98% and 90%). A single motion mode (i.e. N=1, the most dominant motion over the course of an action) provided sufficient information to discriminate between normal and impaired motions.

The high rates of accuracy validate the use of commercially available and affordable vision-based pose tracking technologies in identifying motion deficiencies. This encourages further work into the development of the fully integrated tactile and visual virtual reality system for inducing sensory conflicts and targeted rehabilitation therapy. Future work includes validation experiments with real (i.e. not simulated) impaired motions through testing with actual stroke survivors, real-time exaggeration or attenuation of undesirable synergies, and human subject rehabilitation efficacy trials.

Table 1: *Classification accuracy in distinguishing between normal vs. simulated impaired motion. The algorithm with the best performance in each action category is boldfaced.*

		Classifier		
Action	***N***	**Logistic Regression**	**Support Vector Machine**	**Random Trees**
Reaching Across	*1*	54.3	97.1	**97.9**
	3	61.4	85.7	97.1
Elbow Flexion	*1*	64.3	**95.7**	90.0
	3	59.3	85.0	92.9

The correlation coefficient (ρ) between the sequence of 70 numbers further illustrates the agreement between the two human annotators ($\rho_{h1\text{-}h2}$ = 0.98) and the disagreement between the human annotators and the 3D data ($\rho_{3D\text{-}h1}$ =0.20 and $\rho_{3D\text{-}h2}$ = 0.15). The smaller coefficients indicate that the angles computed from the 3D skeletal joints not only underestimated the shoulder elevation angle, but also were less correlated with the true elevation angle.

Finally, the Student's t-test and its non-parametric equivalent, the Wilcoxon signed rank (WSR) test, also rejected the hypothesis that the 70 angles computed from the 3D joints were taken from distributions with the same mean (or median in the case of the non-parametric test) as that of the 2D angles, while strongly confirming that the sequence of the two human annotators indeed were from the same distribution.

The NITE skeleton tracking library provides a 3-value {0, 0.5, 1} confidence level for each estimated joint position, where 1 is the highest confidence and 0 is the lowest. The confidence values of the estimated position of both shoulder joints, provided by the skeleton tracking library, were at the maximum level (1) in all 70 frames. In other words, any discrepancy between the 3D tracking data and the 2D annotations could not be attributed to low confidence tracking.

4.2 *Discussion*

The results in assessing the tracking of an elevated shoulder highlight the need for a better understanding of the algorithms applied in the skeleton tracking libraries and their underlying assumptions if their usage is to become more widespread in gait and posture assessment. It is interesting, however, to note that despite the inability of the system to track an elevated shoulder joint properly, the developed posture categorization system worked well with a high accuracy of 95.7%. This was only slightly lower (1.4 percentage points when using SVM) than the accuracy rates obtained in identifying trunk rotation. Perhaps even the slight elevation

detected in the placement of the shoulder, combined with other cues from the orientation of the shoulder-elbow and other segments, was sufficient in detecting this compensation mode. It is, however, reasonable to assume that better skeleton tracking would improve the overall identification of compensations.

5. CONCLUSIONS AND FUTURE WORK

When observing short scripted motions, the most dominant mode of motion, as identified by PCA, provided sufficient information to discriminate between normal and simulated impaired motions with high accuracy. Inherent biases were observed in the tracking of an elevated shoulder via the Kinect sensor. The automatic detection of an impaired motion involving an elevated shoulder was only marginally affected by this bias. However, further research in identifying and quantifying such biases is required so that they can be taken into account when designing rehabilitation and health monitoring systems that use the Kinect.

Current work in completing the first phase of the research focuses on experiments with post-stroke survivors to validate the results obtained in classifying simulated impaired motions. Future work towards the full implementation of the sensory-conflict rehabilitation system involves the real-time augmentation of impaired motions, duplicating the rubber hand illusion in a virtual environment via real-time tracking and simultaneous touch feedback, combining the rubber hand illusion with the mirror box illusion via real-time motion augmentation, and clinical trials.

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User-centered development of a virtual reality cognitive assessment

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ABSTRACT

In recent years user-centered design, participatory design and agile development have seen much popularity in the field of software development. More specifically, applying these methods to user groups with cognitive and motor disabilities has been the topic of numerous publications. However, neuropsychological assessment and training require special consideration to include therapists and brain-injured patients into the development cycle. Application goals, development tools and communication between all stakeholders are interdependent and outlined in a framework that promotes elements of agile development. The framework is introduced by example of a virtual reality cognitive assessment for patients with traumatic brain injuries. The assessment has seen a total of 20 iterations over the course of nine months including changes in task content, task difficulty, user interaction and data collection. The framework and development of the cognitive assessment are discussed.

1. INTRODUCTION

Virtual reality (VR) applications have been successfully applied in a wide range of clinical scenarios (Koenig, 2012; Riva, 2005; Rizzo et al., 2010; Rose, Brooks, & Rizzo, 2005). Their strengths and capabilities have been described numerous times (Rizzo & Kim, 2005; Rizzo, Schultheis, Kerns, & Mateer, 2004). One of the main weaknesses of virtual environments, their immature engineering process (Rizzo & Kim, 2005), has seen much improvement by two recent advances in software development. Continuous innovations in computer technologies and the availability of new software development methods have contributed to VR applications becoming more accessible to researchers and clinicians. Especially the rise of computer games and game engines has spurred a vast growth of the number of development tools available to researchers (Siwek, 2007; Trenholme & Smith, 2008). With such tools the rapid development of virtual environments and clinical tasks can be achieved (Koenig et al. 2011, Koenig, 2012).

Agile software development (Beck et al., 2001; Cohen, Lindvall, & Costa, 2003) and techniques such as participatory design (Astell et al., 2009; Bruno & Muzzupappa, 2010), co-design (Dewsbury et al., 2006; Francis, Balbo & Firth, 2009; Freudenthal, Stüdeli, Lamata & Samset, 2010) and user-centered design (Fidopiastis, Rizzo & Rolland, 2010) have been successfully applied towards the creation of VR and health care applications.

An agile development method can best be established by continuous communication between software developers, clinicians and patients. By iteratively adapting the application requirements to user feedback and needs, the development process remains flexible throughout the application's lifecycle. Working software should be put into the hands of users as early as possible during development while minimizing the time needed to write documentation or make elaborate plans for the software's future iterations (Beck et al., 2001).

In line with agile development, a multitude of design methodologies has been published recently that give the user a central role in the development process. User-centered design places its focus on defining requirements and building software that is relevant to the users and their problems. For example, Gabbard, Hix and Swan II (1999) distinguish a behavioral and constructional domain when developing virtual

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environments. User interaction and the user's view of the developed system are represented by the behavioral domain. Due to the immersive and possibly multimodal nature of virtual environments the authors provide guidelines and protocols for usability testing and heuristic evaluation of virtual environment characteristics.

Most participatory approaches focus on the inclusion and communication with patients and caregivers throughout the development cycle. For example, Astell and colleagues (2009) describe such method for the design of computer-based support systems with dementia patients and their caregivers. They depict the communication process and the special considerations that are required when working with a user population with cognitive impairments. The authors name their approach user-centered in nature and describe how the user is actually involved in the design and evaluation process. This is a situation where the distinction between different methodologies becomes vague and methods and their respective names overlap.

Participatory design and also co-design have often been described as actively involving the user in the design and development process of a product or system instead of just adapting the outcome to the user's needs. This can be achieved by exploring the user's habits and problems, discovering solutions together and iteratively prototyping solutions with the user until an appropriate solution to the user's problems has been achieved. Spinuzzi (2005) lays out the details of such methodology, its limitations and how it can be evaluated. A systematic co-design approach for designing technologies for users with autism spectrum disorder is described by Francis, Balbo and Firth (2009). In a structured evaluation by a panel of seven autism experts a set of guidelines has been identified that addresses the use of design techniques and co-design management when working with individuals with autism spectrum disorders.

Fidopiastis (2006) and Fidopiastis, Rizzo and Rolland (2010) describe a user-centered design approach by benchmarking immersive technologies before using them for cognitive rehabilitation application. This approach is aiming to increase validity of virtual reality assessments. The authors base their user-centered practices on the ISO13407 guidelines which have since then be revised by ISO9241-210:2010 "Human-centered design for interactive systems". These standards again put heavy emphasize on understanding and involving the user throughout the iterative development cycle.

All of the described development methods highlight the importance of including the user into the development process, both at the design and testing stages. Each existing publication focuses on specific application areas or user group such as patients with dementia (Astell et al., 2009), autism spectrum disorder (Francis et al., 2009) amputees (Cole, 2006) or cognitive rehabilitation in general (Fidopiastis et al., 2010). It becomes apparent that each clinical domain poses its own unique challenges for the development process, especially with regards to the patients' ability to partake in the design and evaluation process as outlined by traditional user-centered and participatory design guidelines. Francis and colleagues (2009) particularly highlight this discrepancy by contrasting symptoms of autism spectrum disorders with the requirements for contributing to the participatory design process. The authors conclude that the co-design method can be much more difficult with users with autism spectrum disorders. Though, the selection of appropriate methods and tools that empower the users during the design process can greatly facilitate the designer – user interaction.

It is the purpose of this paper to outline methods and challenges for user-centered design in the domain of neuropsychological rehabilitation. The development of VR applications for neuropsychological training and assessment requires additional design factors to be considered. The overview in the following chapters provides details of such factors and their influence on development, testing and communication between involved stakeholders. An example for applying such framework to a VR assessment for patients with traumatic brain injuries is presented and discussed.

2. METHOD

Virtual reality technology comes with a well-known set of strengths and limitations (Rizzo & Kim, 2005). Widely available development tools such as game engines and 3D modeling applications lay the foundation for effective workflows to build interactive virtual environments within days instead of months (Koenig, 2012). However, the availability of such development tools does not automatically provide a standardized way of creating applications that solve existing clinical problems. As previously outlined, user-centered and participatory design provides guidelines for user involvement, but the integration of these guidelines into the actual development process – from project inception to finished product – is left to the developer. This leads to the question of how design, development workflow and user integration can effectively be combined to create applications that provide value in the context of cognitive rehabilitation. The following framework provides an outline of such workflow in the context of a virtual reality cognitive assessment.

An initial exploration of research questions, scientific inquiries, clinical questions or clinical gaps can motivate the design and development of an application that addresses an identified problem or opportunity. A

developer then chooses the appropriate tools and resources to build a virtual reality system that solves the identified problem. However, a virtual reality system potentially consists of a large number of components that include software and hardware elements. Choices for each component have to be made based on the input from several user groups. This is where a communication challenge starts to emerge which is not accounted for in traditional user-centered or participatory design methods. Depending on the purpose of the developed application, a large number of user groups can be involved in the development of such a virtual reality system. For example, a system might primarily be designed for several members of the clinical team who need to administer the application to a patient. More use cases emerge when cognitive assessment and training scenarios are considered that range from one-off usage at a clinic to long-term exposure beyond the scope of inpatient and outpatient rehabilitation. Moreover, communication with individual user groups can be asymmetric such that input from certain user groups is purposely restricted or prioritized over other groups. Exemplarily, patients' knowledge about a neuropsychological assessment sometimes has to be minimized and limited to usability feedback while clinicians can be more directly involved in the design process. In each case individual user groups can either give direct input on design decisions or indirectly provide usage data to inform design choices for different system components.

With such a wide range of scenarios, it becomes apparent that the development process involves numerous decisions with many unknown variables and outcomes. Figure one lists several system components that can potentially be integrated in order to build a complete virtual reality system.

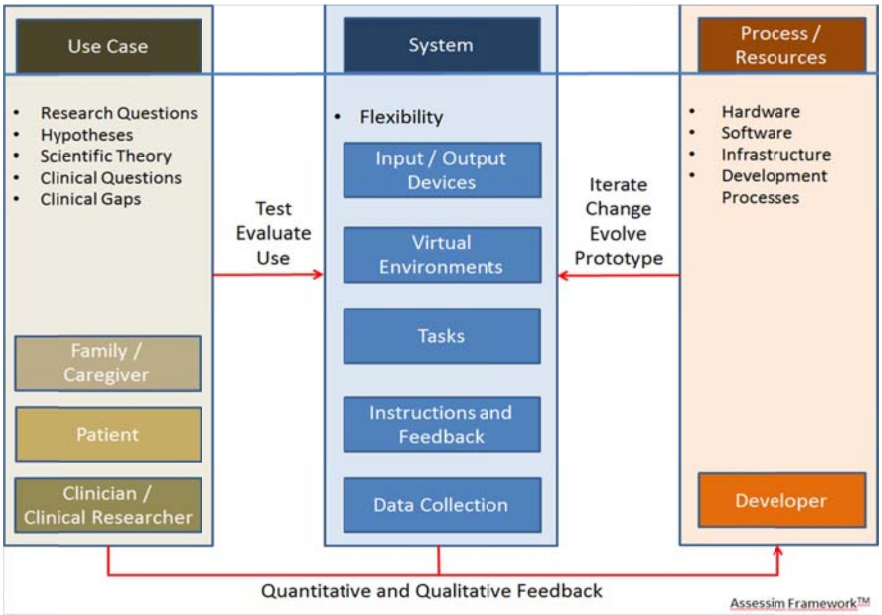

Figure 1. *Development framework for systems of virtual reality training and assessment.*

During the course of system development each component needs to be flexible. The amount of choices available for each component complicates the planning of system specifications prior to the development effort. Hence, agile development methods minimize the initial planning process and produce a simple working prototype based on early input from relevant user groups. Subsequent design decisions can address system components in an iterative fashion while allowing the overall design of the system to remain flexible. This flexibility pays off when system components need to be changed or replaced once the system's outcome data is analyzed for its validity and reliability.

3. SYSTEM DESCRIPTION

Assessim Office is a virtual reality cognitive assessment developed in collaboration with the University of Southern California Institute for Creative Technologies and the Neuropsychology and Neuroscience Laboratory (NNL) of the Kessler Foundation Research Center. The application is based on the Assessim Framework and provides a range of realistic tasks for the assessment of cognitive abilities. The aim of the application is to assess cognitive functions – specifically executive functions – in a complex functional environment. The combination of several tasks of different priorities (e.g. rule-based decision task, reaction time task, divided attention task) is expected to simulate challenging scenarios which are similar to the

demands that are placed on the cognitive system in a real-world work setting. It is predicted that such ecologically relevant task scenario is more sensitive to cognitive deficits of brain-injured individuals and can predict cognitive performance in real-world settings accurately.

3.1 Project Members and Communication

The development of the described framework and its extension for Assessim Office was completed by one virtual reality developer with clinical background. The clinical research team at the NNL consisted of two research scientists, one postdoctoral fellow, three research assistants and several additional staff members. Design decisions were discussed between the virtual reality developer, the research scientists and postdoctoral fellow at the NNL. Direct communication between the developer and the research team consisted of email conversations and Skype calls during which one research scientist was the point of contact for the NNL. Brain-injured patients were only involved in user tests once the initial task design and development were finished. Assessim Office was designed to be a cognitive assessment administered to brain-injured patients with traumatic brain injury. Hence, the early task design was not driven by patient input or user feedback, but rather by scientific theories of human cognition. The researchers at NNL acted as proxies for the patients (Francis et al., 2009) by providing input about the appropriateness of individual system components. A first prototype of Assessim Office was installed on a desktop PC at NNL during an early project meeting. Subsequent updates to the application were exchanged through the filesharing platform Dropbox.

3.2 Prototyping

Initial prototypes of the Assessim Framework and Assessim Office were developed over the course of three months. The framework was developed with the game engine Unity and contained a simple event system to trigger object interactions, audio and visual cues. Further, the saving of text files to the local hard drive was implemented. The office environment for Assessim Office (Figure 2) was created with Google SketchUp as outlined by Koenig and colleagues (2011). Before the first prototype was installed at NNL, a menu system and a practice trial similar to the actual assessment session were developed. The total development time for these prototypes was approximately 100 hours, most of which were spent for modeling the virtual environment. The office scene was chosen for its functional relevance, work-related context and relevance for additional projects.

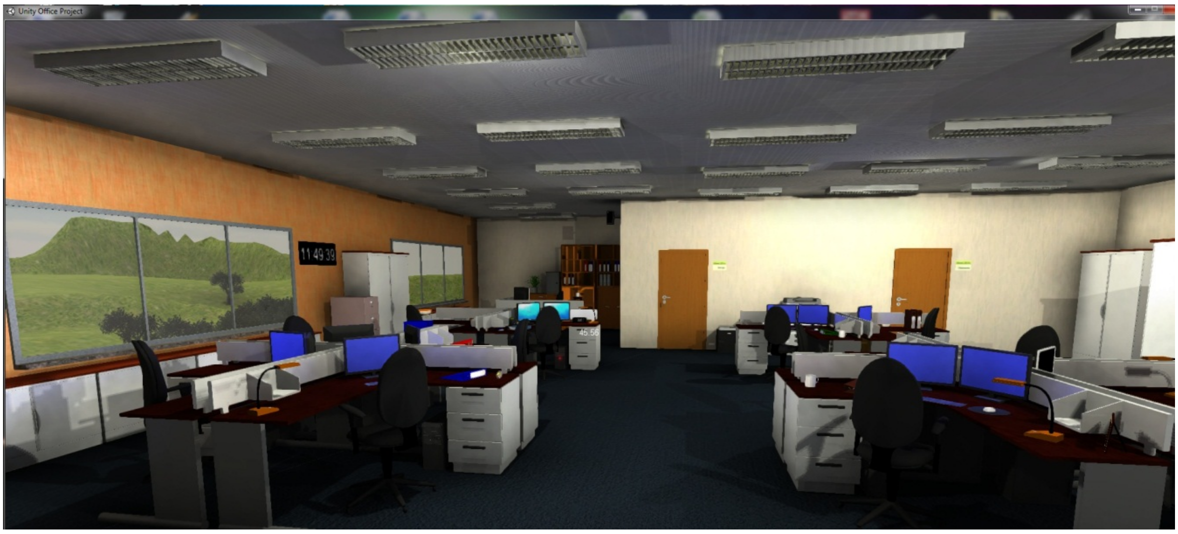

Figure 2. *Virtual office environment rendered in the Unity game engine.*

Each of the system components consisted of a minimally viable solution which is based on lean methods as described by Ries (2011). The goal of the initial prototype was to deliver a simple functional virtual environment to the researchers at NNL. Without any knowledge of how such system can be adapted to the needs of a clinic, research laboratory and patient population, any implementation of features or task content is uncertain and can potentially change several times throughout the development process. The first prototype consisted of mouse and keyboard input, because it was natively supported by the game engine Unity. Output through a standard 24-inch LCD monitor and plug-and-play stereo desktop speakers was chosen due to simplicity, availability and the non-spatial nature of the planned cognitive tasks. The virtual office

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environment and several simple reaction time and decision tasks (i.e. reply to email, respond to ringing phone, make decision about email offer) were implemented for an unrelated experiment. This implementation was based on a simple trigger system which enables the developer to attach a C# single script to any object within the virtual environment in order to make the object interactive (e.g. turn a monitor on and off). Instructions about tasks or user input were not included, because tasks and input schemes were expected to change over time. Data collection capability was recognized a fundamental feature needed for any clinical trial and was supported through saving and loading text files from the PC's local hard drive. The exact content and structure of the saved files was still undetermined.

3.3 Iteration

During December 2011 and July 2012 a total of 20 iterations were developed and tested. On average, the application received an update every 13 days. Average response time between user feedback or design decisions and their implementation in the next update is estimated to be approximately three days. Average development time for each update is estimated to be approximately five hours. Estimations are based on time stamps of file updates and email conversations between developer and point of contact at NNL. However, time estimations are approximated due to developer commitments in several parallel projects. Initial iterations were focused on changes to the task content and user instructions.

Starting after the sixth iteration user testing was extended beyond two research scientists at NNL. Each subsequent update was first screened by the research scientists and later tested with one to two staff members. Each user was encouraged to provide verbal feedback about all system components. A total of seven staff members were tested throughout the development process, three of whom were repeatedly exposed to the application. During these early iterations adjustments to task content, task instructions, audio feedback and user interaction were made.

The ninth iteration added a divided attention task during which the user has to turn a projector on whenever it overheats. The locations of the projector and projector remote control require the user to turn their attention away from their virtual desk on which all other tasks are positioned. This task was also intended to increase overall difficulty of the virtual assessment in order to avoid ceiling effects. Further, user interaction with a joystick was added. It was expected that the navigation through the virtual office was made more intuitive by the use of a joystick. However, early feedback by researchers and several staff members confirmed that using a computer mouse was more efficient and intuitive for interacting with items within the virtual environment.

Iterations nine to thirteen were focused on updates to each of the cognitive tasks. Frequency and timings of phone rings, email responses and decision-making tasks were adjusted to provide an adequate challenge for healthy users. Task events were timed to overlap so that the user had to make decisions on which task to prioritize. Most development time was spent on testing the exact timings of the tasks.

During the thirteenth iteration a major change to the cognitive tasks was implemented. During discussions between developer and researchers it became apparent that the combination of cognitive tasks did provide an adequate pacing but did not measure the underlying cognitive construct that it was expected to measure (i.e. executive functions). Too many reaction time tasks that did not require decision-making or inhibition of false responses were implemented. Within eight hours of development several tasks were removed and a new task was added to the system. This change was made possible by the flexibility of the development process which only required the scripting of the new task within the task component of the outlined system (Figure 1). Answering phone calls was completely removed from the assessment and phone rings were now solely used as distractions. Printing documents was also removed as a standalone task and integrated into the decision-making task. The complexity of the rule-based decision making task was increased to balance the overall difficulty of the assessment. The user now had to evaluate incoming email offers based on several criteria and accept or decline them. Further, based on a different criterion the user had to print the incoming offer and place the printed document at a predefined location. The interference of criteria for both tasks was intended to assess the user's ability for inhibition of dominant responses. A new virtual character was added to the scene to plausibly explain the printing of incoming offers.

During the following iterations minor changes to data saving, instructions and difficulty to the newly implemented task were made. Again, most of the development time was spent on balancing and testing task difficulty. During iteration 19 and 20 the application was first pilot-tested with brain-injured patients. Also, iteration 20 addressed feedback of staff members experiencing dizziness during conducted test trials. Environmental factors and user interaction were discussed with the developer and the rotation speed of the virtual camera was reduced to prevent sudden viewpoint changes. User feedback suggested that the camera moved too fast while the user was getting accustomed to the input scheme during practice trials. Instead of

testing several rotation speeds separately a speed control was implemented that allowed the research scientists to change camera rotation speed while the application was running in order to find the optimal setting for users to be comfortable.

Future iterations are expected to address bugs and critical feedback from patient trials. Further changes are anticipated once all patients have been tested and validity and reliability analyses have been applied to cognitive task outcome measures. The system's task and data collection components can then be adapted to improve the tasks' validity and clinical value as a cognitive assessment.

Figure 3. *Extended office environment rendered in the Unity game engine*

3.4 Summary

The Assessim Office cognitive assessment has undergone extensive iterative design and testing. During the course of 20 iterations four out of the system's five components have been modified and improved considerably. The system is currently being tested as an outcome measure for three clinical trials at the NNL of the Kessler Foundation Research Center. Four research assistants were trained with the application and are currently administering it to brain-injured individuals. Patients with traumatic brain injury and multiple sclerosis are providing valuable feedback by using the application in conjunction with standardized neuropsychological measures of attention, memory and executive functions. Throughout the design and development process the system remained simple and flexible so that changes for each individual component were easily implemented without affecting other components. Future iterations are expected to further improve the system's psychometric properties and test different options for input, output and data collection. Motion controllers (e.g. Microsoft Kinect, Leap), Head-Mounted Displays and visual data representations (e.g. after action reviews) are planned for future implementation.

4. CONCLUSIONS

Assessim Office is a cognitive assessment that has been designed and developed as part of a framework based on agile and user-centered design. The system is targeted at two user-groups – brain-injured patients and clinicians. Such complex user relationship (e.g. clinicians assessing patients) requires combinations of user-centered and participatory design. Clinical researchers at the Kessler Foundation Research Center were actively participating in the design and testing of the application. Brain-injured patients were only included in user testing after a total of 20 iterations and approximately six months of development. Design and user testing were asymmetric for both user groups because of the evaluative nature of the system and scientific grounding of the task content. The design and development processes were based on elements of agile methods. A wide range of changes to each of the system's components were made within only few hours of development. A working prototype was tested shortly after the beginning of the project. Due to the large amount of potential choices for each of the system components, no detailed plan for the finished system was made at the project outset. Instead, incremental changes to individual system components (e.g. input device, task frequency) were implemented and tested rapidly. Assessim Office is currently being used as outcome measure in three clinical trials. Based on patient feedback and results of validity analyses the system's components will likely undergo further iterations.

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An extension of the current system is being developed by replacing the virtual environment with a larger office building. The building provides a more complex layout in order to assess the user's navigation ability. Additionally, a large number of interactive virtual characters are added to simulate a realistic, distractive work environment for cognitive assessment (Figure 3). Due to the flexible system architecture such extension only requires a change in art assets and the adaption of the cognitive tasks to the new environment. All other system components remain identical. Consequently, the described framework allows the developer to deploy a large number of cognitive assessments, each customized to a specific environment which is relevant to the assessed patients and users. This approach extends the context-sensitive clinical framework as described by Koenig (2012).

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User perspectives on multi-touch tabletop therapy

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ABSTRACT

Technology-based activities are becoming increasingly popular in therapy programs. In particular, multi-touch tabletops seem to be well suited for many therapy activities. To better understand the benefits of using multi-touch tabletops during rehabilitation, we examined users' attitudes towards rehabilitation activities on a multi-touch tabletop and on a non-interactive surface. Using a standardized questionnaire and semi-structured interviews, we identified many advantages and limitations of using multi-touch tabletops in rehabilitation. We discuss the implications of user expectations and experiences on the design of future activities.

1. INTRODUCTION

Multi-touch tabletops have become increasingly important therapy tools. Interactive tabletops and other direct-interaction devices have several advantages (Hutchins et al., 1985) that make them excellent candidates for new rehabilitation technologies. They are believed to be useful for regaining function and motor ability in patients recovering from strokes or traumatic brain injuries because they encourage lateral upper-body movement (Annett et al., 2009, Mumford et al., 2008; Wilson et al., 2007). Multi-touch tabletops support natural and direct interaction (Wigdor and Wixon, 2011). That is, the user touches and manipulates an object or target directly instead of using a proxy device such as a mouse, keyboard, or joystick for interaction. As patients with cognitive disabilities often have trouble creating a mapping between a proxy object and target, this direct interaction provides an important advantage. Interactive tabletops also provide a large interaction space, which is needed for many patients to exercise gross motor function and fully explore their entire range of motion. Such interaction is not possible on small hand-held devices. Lastly, tabletops have the ability to support a patient's upper-body weight while performing an activity, thus allowing patients with varying abilities to benefit from activities.

Outside of tabletop-based therapy, it has been widely recognized that patient motivation and patient compliance with rehabilitation exercises are critical problems. Most recently, therapists have turned towards technology to address these problems (Holden, 2005; Crosbie, 2007). One approach to encourage compliance and increase motivation has been to use video games, as it is believed that patients can become as highly engaged with their therapy exercises as video game enthusiasts are with their games (Rizzo and Kim, 2005). Thus, various gaming technologies such as the Microsoft Kinect (Chang et al., 2011; Lange et al., 2012), PlayStation EyeToy (Rand et al., 2008), and Nintendo Wii (Saposnik et al., 2010) have become pervasive in therapy programs (Flynn and Lange, 2010).

Previous studies on tabletop-based therapy (Anderson et al., 2012; Mumford et al., 2008; Annett et al., 2009) have focused on the movements produced by users, and have not considered the equally important aspect of user experience. Recently, it was found that the structure of activities has more influence on participant movement than the use of technology (Anderson et al., 2012). These results emphasize that the strength of technology must be in improving motivation and compliance and demonstrate the need for the effective and informed design of activities. Not only must multi-touch therapy activities be engaging and compelling, but the challenges such technologies present in clinical settings must also be addressed. The usefulness of direct-touch interaction and expectations that patients may have as a results of using similar devices (e.g., smartphones, tablets, and touch screens), are both important factors that the present study investigates.

In this paper, we examine user's subjective impressions towards tabletop-based therapy activities. We conducted an experiment in which participants were exposed to two 'traditional' therapy activities, as well as two multi-touch tabletop-based therapy activities. Participants completed standardized questionnaires and

took part in a semi-structured interview to assess their subjective views on the therapy activities and use of technology in therapy. Overall, participants enjoyed the technology-based activities, but were unsatisfied with some aspects of the technology activities. The results were then used to create a collection of design recommendations to help designers provide patients with rich, immersive experiences.

2. EXPERIMENT

2.1 Participants

As patient safety is of great concern when evaluating any new treatment, this study examined healthy participants. Although the healthy and disabled populations differ with respect to age or physical abilities, many valuable observations gathered from the healthy population should also be applicable to clinical populations. We recruited seven males and seven females (18-77 years old) to participate in the study. Each participant was right handed and had no prior experience with a multi-touch tabletop. The University of Alberta's Research Ethics Board approved the study.

2.2 Equipment

The technology-based activities in this study used a custom-built multi-touch table (Annett et al., 2009) that employed Frustrated Total Internal Reflection (FTIR) for sensing (Han, 2005). The acrylic surface of the table was approximately 80 cm above the ground and had a 91 cm x 61 cm region of interaction. The tabletop consisted of a projector, mirror, and an infrared camera. Infrared light sources were embedded around the perimeter of the acrylic display surface. Being FTIR-based, the tabletop is not as responsive or accurate as smaller-scale commercial devices that use capacitive sensing (e.g., iPhone, iPad), but is still very usable and responsive, especially when interacting with larger targets (such as those used in this study). The openFrameworks toolkit was used to process the raw video stream and determine when and where a user was touching the surface. Each of the technology-based therapy activities was written using Adobe Flex.

For the traditional, non-interactive activities, a white, corrugated plastic board (91 cm x 61 cm x 0.4 cm) was placed on top of the acrylic surface of the multi-touch tabletop. The repurposing of the multi-touch tabletop in this way allowed participants to remain in the same location and use the same region of interaction across all activities.

2.3 Task

Participants stood in front of the multi-touch tabletop and completed four activities (Figure 1), two using the multi-touch tabletop (*Memory* and *Puzzle)* and two using the traditional, corrugated plastic surface (*Card Sorting* and *Grid of Stickers*). All four activities were comparable to activities currently used by patients at a local rehabilitation hospital and encouraged similar movements.

- The *Memory* activity presented participants with a grid of 40 tiles, each with the same image. When a participant touched a tile with their index finger, the tile would 'flip' over to reveal an image hidden on the underside. The object of the activity was to match tiles with identical hidden images by touching them sequentially. If a pair was matched correctly, the tiles disappeared; if two tiles were touched and they did not match, they flipped back to hide the underside images. The activity ended when all tiles were matched.
- The *Puzzle* activity was designed to be very similar to assembling a real tile puzzle. The participant was presented with 45 rectangular 'pieces' that were distributed randomly across the screen. To join matching pieces together, participants slid matching pieces next to each other so that they would 'snap' together. Once all the pieces were assembled (into a 9 piece x 5 piece picture), the activity was over.
- The *Card Sorting* activity used a set of miniature playing cards and a 10 x 4 grid drawn that was drawn on the corrugated plastic surface. Participants were told to sort the cards into ascending order (ace through ten) by suit and slide them up onto the grid. They were allowed to move the cards into place in any order, but were instructed to use only their index finger to slide them and were not allowed to pick them up off of the surface. This restriction was put in place to increase the similarity between the movements on the interactive surface and the traditional activity. Once all of the cards were placed in order, the activity was complete.
- The *Grid of Stickers* activity required participants to touch each of the 45 numbered, colored sticker targets sequentially. Participants had to touch all targets numbered '1' in the appropriate order (i.e., Brown, Pink, Blue, Yellow, Green) before moving on to the targets numbered '2' and touching them in the appropriate color order. Once participants touched all the targets from '1' through '9', the activity was complete.

Participants performed each activity for 5 minutes, with the order of activities randomized between participants. If participants finished the activity before the allotted time elapsed, the activity was reset and the participant repeated it until 5 minutes elapsed. A short 3-minute break was allowed between activities to mitigate possible fatigue effects and allow for the next activity to be set up. Similar to constraint-induced movement therapy (Kunkel et al., 1999; Taub et al., 2004), participants were restricted to use only their dominant (right) arm to complete each activity.

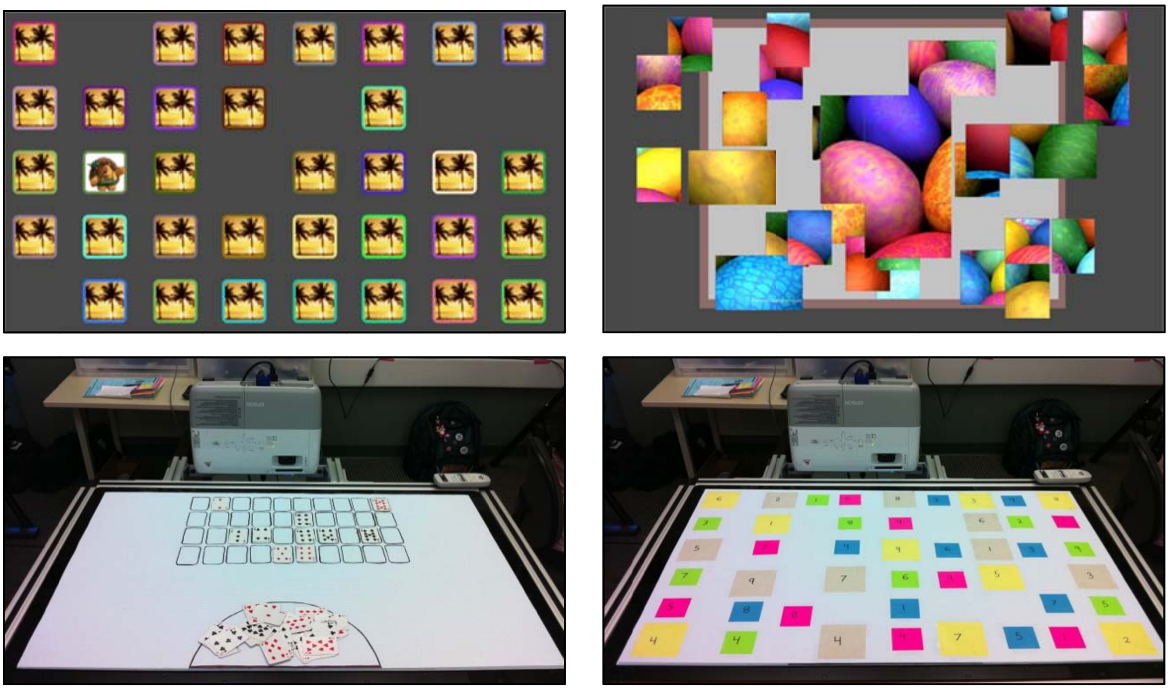

Figure 1. *(Clockwise from top left) The four activities used in the study: Memory (in which participants touched virtual tiles to 'flip them' and reveal images underneath that must be matched), Puzzle (in which participants had to slide tiles on the screen to assemble a large picture), Card Sorting (in which participants had to slide physical cards into ascending order, by suit, onto the grid) and Grid of Stickers (in which participants repeatedly touched the tiles in order, by color).*

The Intrinsic Motivation Inventory (IMI) (McAuley et al., 1989) was used to assess participant's subjective opinions towards the traditional tabletop activities and the multi-touch tabletop activities using Likert-type responses to statements such as "I would describe the activities as very interesting". From the responses, scores along four separate dimensions (i.e., interest and enjoyment, effort and importance, mental tension and pressure, and perceived competency) were computed and represent the participant's subjective feelings towards the different activities. Two separate inventories were administered, one assessing both of the traditional activities (*Card Sorting* and *Grid of Stickers*) and the other assessing both of the technology-based activities (*Memory* and *Puzzle*). At the conclusion of the experiment, a semi-structured exit interview was conducted. The interview lasted approximately 5 minutes. The following guiding questions were used during the interview and participants were encouraged to engage in open discussion to explore topics not covered directly by these questions:

- Which activities did you enjoy the most? Enjoy the least?
- If you could change any of activities, what would you change?
- Which category of activity (traditional or technology) did you prefer?
- Imagine you are in a therapy program. Which of the activities would you prefer to use?

3. RESULTS AND DISCUSSION

The Intrinsic Motivation Inventory responses (Figure 2) were analyzed using Bonferroni-adjusted, Wilcoxon signed-rank comparisons. Participants rated the multi-touch activities (*Memory* and *Puzzle*) as significantly more interesting and enjoyable than the traditional activities (*Card Sorting* and *Grid of Stickers;* Z = 2.79, p = .0052). There were no significant differences along the other dimensions (i.e., effort (p = .45), competence

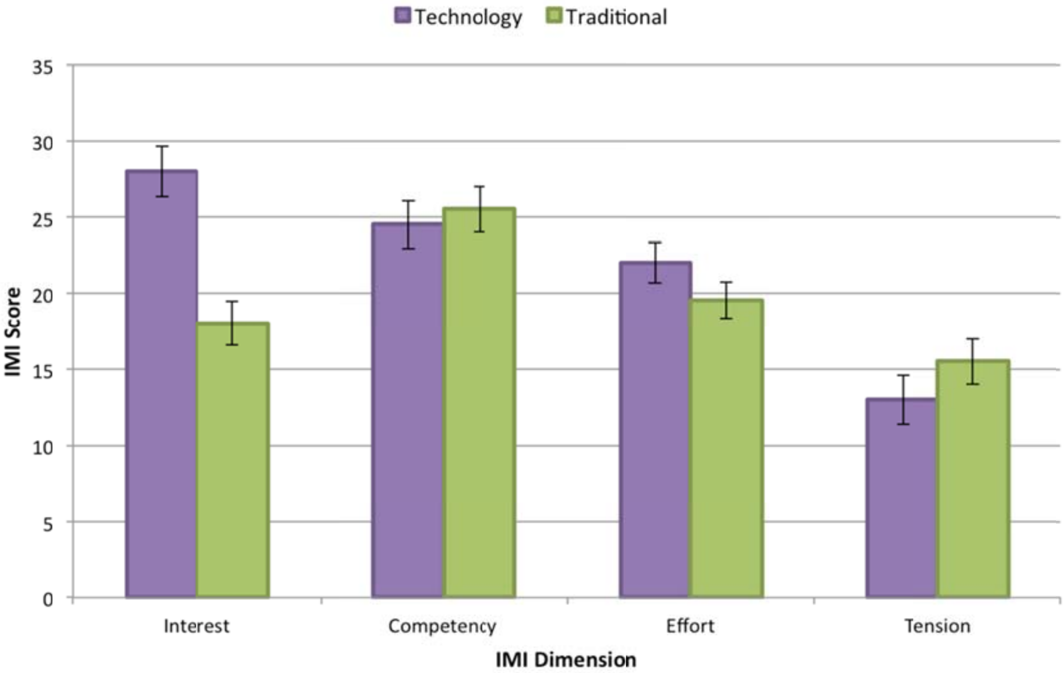

Figure 2. *The median scores for each of the dimensions of the IMI. Error bars depict the standard error of the mean. The 'Interest' dimension is statistically higher with the technology-based activities (i.e., Memory and Puzzle) than with the traditional activities (i.e., Grid of Stickers and Card Sorting).*

(p = .71), and tension (p = .68)). As all four of the activities were quite simple and participants were instructed to perform each activity at their own pace, the lack of statistical differences among the remaining dimensions is unsurprising.

The semi-structured interviews help to explain the reasons behind the increased scores of enjoyment and interest. Several participants commented that they enjoyed the technology-based activities more because they contained dynamic elements and feedback about their interaction with the surface: "hearing the puzzle click together and having the tiles disappear in front of me was super motivating" (P1) and "I liked getting the feedback of the noise and the sounds, it motivated me to go faster and do more" (P3). Although the activities were completed individually, many participants mentioned that they took a competitive stance towards completing them, "[the tech] wasn't frustrating at all! For me it was like a competition" (P10). While using the multi-touch tabletop, several participants also indicated that they felt as if they were being motivated to accomplish a worthwhile goal: "I like the puzzle one because you're actually playing a game and trying to finish something instead of just touching stickers" (P3).

These comments suggest that technology-assisted rehabilitation might be more enjoyable because it provides meaningful, achievable challenges and real-time, dynamic feedback to users. The feedback from participants is consistent with beliefs that dynamic gaming elements lead increased enjoyment and adherence to therapy programs. When designing activities for therapy, it is not enough to simply rely on the use of technology to increase engagement and improve adherence to a therapy program. It is important for designers to think carefully about the goals of the activities they are designing and employ feedback at the correct frequency, using the correct medium, and at an appropriate cognitive level. Designers should also work to provide engaging, and challenging (yet accomplishable) elements within their activities that are intrinsically motivating to patients.

Other comments alluded to the role that prior exposure to technology (specifically multi-touch technology), had on participants' expectations and experiences with the multi-touch tabletop. Many participants compared the multi-touch tabletop (and its activities) to commercial multi-touch devices: "if you have an iPad you can see that it registers every motion and gesture ... the design of [iPad] games are better" (P13); "I'm just so used to playing those iPhone games" (P12). Many participants expressed that they would definitely prefer to use the multi-touch tabletop in a rehabilitation setting if it was as refined as the commercial products they use every day in terms of sensing responsiveness, the quality of game design, and the selection of games available.

As the quality of commercial technology increases but the budgets for therapy-driven software remain comparatively low, these observations become particularly relevant. The user-facing aspects of therapy software need to be improved to meet the growing expectations and familiarity patients of all ages will have with multi-touch technologies. In the near future, many patients will be intimately familiar with software products and video games released by large production studios with equally large budgets. Unfortunately, custom therapy-targeted projects will likely not have these budgets so designers will have to be creative in finding ways to meet such expectations. To create engaging, high-quality games at low costs, designers should leverage existing content and technologies where possible, and use openly available video-game engines to ensure that rehabilitation games do not feel similar to ad-hoc prototype applications, instead appearing robust, well designed, and thoroughly tested.

Several participants were also quick to cite technology (i.e., the multi-touch tabletop), instead of themselves as the source of any errors that occurred. As the multi-touch tabletop provides direct-touch interaction, there is a much smaller gulf of execution than with indirect-touch interfaces (Hutchins et al., 1985), thus causing more ambiguity with regard to the source of errors. During our experiment, the largest sources of frustration were situations in which false touches were detected and situations in which the user received little or no feedback. When this occurred, many users were unsure if they were not touching the surface with enough force (even though it was not pressure sensitive) or if they were not touching the surface in the right location. This often led to confusion and annoyance. For example, one participant was "irritated at how the tabletop wasn't too responsive" (P7) and continually exerted more force on the surface. In contrast, none of the participants complained about the mechanics of the traditional activities when they made an error and one participant commented that they "felt [they] could handle the physical materials more easily than the digital ones" (P8).

To minimize user frustration during input, tabletop activities must have responsive sensing and accurate feedback, as users will otherwise become quickly irritated and feel as if they are not in control of an activity and potentially their therapy progress. While hardware is a large determinant of the responsiveness and accuracy, some steps can be taken in software to reduce the apparent effects of these parameters. For direct-touch devices with coarse sensing resolution (or noisy sensing), on-screen targets can be made larger so that pixel-level accuracy is not required. Feedback should also be used to indicate the exact location where a user's touch was registered. Such feedback will allow users to adjust their interaction to accommodate for any offsets or input warping and will help reduce the ambiguity caused by positioning errors. To mitigate latency issues, developers should ensure that feedback regarding a sensed touch is displayed as soon as possible and not delayed by complex application-specific processing. If complex processing is required, the system should first provide feedback about where the touch was registered before processing the application-specific response.

4. CONCLUSIONS AND FUTURE WORK

Given the previous work demonstrating that technology itself is not enough to modify the movement patterns of individuals in therapy programs, it is clear that the benefit of technology lies in its ability to provide responsive, dynamic content. This content and feedback plays a strong motivational role, which can encourage patients to perform their normally monotonous therapy tasks for a longer duration, and possibly with more effort. To that end, we have studied user attitudes comparing interactive tabletop-based rehabilitation and traditional static-surface rehabilitation and found that while users do typically find interactive activities more engaging, there are many limitations that must be overcome before multi-touch tabletops can become truly beneficial tools for use with clinical populations.

There are several avenues along which this work can be extended. One next step is to refine our activities based on the observations gathered during the current study and perform a long-term study with a patient population. While we expect many of our conclusions and recommendations to generalize to both populations, studying the usage behavior of the actual target end users (i.e., patients) will likely produce additional insights that will be of great value. Additional future work could also involve studying those aspects of tabletop-based therapy that contribute to success and enjoyment for the end user, for instance, examining the relative importance of customization, dynamic feedback, and differences in game content (i.e., emotionally salient content). Other work could further examine the role of patient expectations towards technology and investigate ways in which future multi-touch activities can be created on smaller budgets and still meet or exceed patient expectations.

This study has revealed important insights into multi-touch therapy activities. While direct-touch interaction offers a number of benefits when used in therapy-based activities, there are a number of drawbacks that should be addressed. Using our design recommendations, the engagement and enjoyment

patients experience during therapy can be improved and it is our hope that this will lead to higher motivation within patients and ultimately encourage patients to comply with the therapeutic activities that they are prescribed.

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Development of a complex ecological virtual environment

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ABSTRACT

Virtual environments (VEs) provide clinicians and researchers an opportunity to develop and implement an engaging, ecologically valid, complex, life-like interactive 3D simulation, which can be tailored dynamically to characterize and precisely measure functional behaviour in response to different multisensory stimuli. Complex ecological VEs that are based on familiar real-world environments enable participants to relate to the training environment which in turn, may promote translation of functional improvements to real-world tasks. This study describes the development of a systematic and context-specific complex VE using simple computer graphics and modelling tools.

1. INTRODUCTION

Virtual reality has been defined as the "use of interactive simulations created with computer hardware and software to present users with opportunities to engage in environments that appear and feel similar to real-world objects and events" (Rizzo and Kim, 2005; Weiss et al., 2006). Recent technological advances have enabled virtual environments (VEs) to be developed and used as clinical tools for rehabilitation (Bohil et al., 2011; Rizzo and Kim, 2005). Various simulation technologies permit the development of VEs that may be presented via different forms of visual display devices and operated via interface devices which allow the user to interact and engage in tasks within the environment. VEs also provide the capability to modify the nature and pattern of feedback given to the participant in real-time. VEs thus enable clinicians and researchers to create ecological client-specific contexts that can be controlled and modified dynamically in order to study different aspects of motor and cognitive abilities.

Recent advances in game console systems have provided researchers with the opportunity to employ low-cost, off-the-shelf VEs. In addition, simulation tools such as NeuroVR2 (Riva et al., 2011) provide non-expert users the capability to adapt pre-designed VEs based on the parameters of the clinical or experimental setting. NeuroVR2 includes features such as collision detection to control interactions of the user with objects in the environment and customizable task parameters. However these capabilities may seem limited to clinicians or researchers interested in assessing cognition in complex real-life scenarios. There is thus a need to provide additional tools to enable clinicians and researchers to develop context-specific simulation tools which are guided by the underlying goals of clinical rehabilitation.

Lewis (2012) suggested that to enhance engagement and increase motivation of the user, developers and designers need to take into account end user needs and expectations. One of the most important questions in designing simulated tasks for a complex VE is how the performance skills acquired in the tasks transfer to performance in the real world. It is essential to construct VEs that address this question by exposing participants to tasks that are challenging, progressively adaptable, motivating and, in particular, meaningful with respect to a real life-like environment. Other issues, such as the promotion of participation and socialization within the environment, and the correspondence between real life and virtual motions may also impact on how community-based, chronic disease populations respond within the VE. Moreover, it is

important to design simulated tasks within complex VEs that enable task-based therapies that entail a high degree of repetition and duration (Kleim and Jones 2008; Rizzo and Kim, 2005).

The creation of a versatile and contextually rich VE is typically a long and costly developmental process. In addition, the resulting scene may not necessarily reflect the complex situations usually present in the physical environment nor give precise control over key variables in the simulation (e.g., user interaction with virtual objects). Clinicians, researchers and end-users (clinical population) thus need to be involved in the development process of the VE, to provide the developer with feedback on ways to customize the VR with respect to individual rehabilitation goals.

Recent research by Koenig et al. (2011) has demonstrated the feasibility and usability of context-sensitive VEs which depict scenarios that are meaningful to the client, reflecting the complex situations with which they have to cope upon their return to the community. They described the requirements for using VEs in rehabilitation and detailed the workflow needed to rapidly develop such VEs. This involved taking real world measurements to model the VE to scale and creating a simulation that was adapted as a client progressed throughout the training program. The simulation development study described in the current paper concerns the use of a similar workflow to create a complex VE of a section of a large urban shopping mall using simple computer graphics and modelling tools. This was conducted as a pilot study in support of a large-scale, multidisciplinary research project to create a "Rehabilitation Living Lab" within the setting of the same urban shopping mall. The Living Lab aims to comply with Følstad's (2008) objective of using the principles of participatory design to identify true user behaviour to optimize social inclusion of persons with disabilities by creating enabling physical and social environments.

The objective of the present study was to use simple graphics and modelling tools to create a realistic, functional VE of a section of a large shopping mall, modelled to scale in order to demonstrate the feasibility of using complex ecological environments in rehabilitation training paradigms. The VE was designed to enable a researcher or clinician to readily include a variety of functional tasks (e.g. start/end locations, target items, time for individual tasks etc.) that can be used to identify and provide metrics about the user's cognitive and motor abilities.

2. METHODS

The workflow described in the present study was inspired by and adapted from that originally proposed by Koenig et al. (2011). It consisted of taking pictures and measurements of the real environment to create a 3D model, and exporting the model into a game engine in order to design navigation and performance tasks. The primary focus of the current study is to describe the individual components of the workflow, and their advantages and drawbacks when designing large complex environments such as enclosed sections of a shopping mall.

2.1 First step: Visiting the real-world environment

Complex social environments such as shopping malls incorporate numerous components other than stores including shopping kiosks, magazine stands and structural components such as pillars and architectural fixtures. It is extremely important to capture precise details of these individual components as they combine together to form a real-world environment. The first step consisted of visiting the section of the mall to be modelled and taking high-resolution photographs using a digital camera. The settings of the camera were adjusted (aperture-priority mode with a smaller aperture f16/f22 and slow shutter speed) so that any moving objects in the scene were blurred giving a clear view of the background. The photographs of the different structures were taken from different vantage points resulting in a complete 3D depiction of the environment. They were then sorted to create a logical flow of the scene, and also to create a panoramic view of the environment as shown in Fig. 1.

Figure 1. *Panoramic view of the shopping mall created from a series of photographs.*

The photographs were taken at a high resolution since they were used to create individual textures by the 3D modelling program. That is, relevant portions of the photographs were extracted and then corrected for

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distortion and enhanced using Adobe Photoshop. Floor plans of this section of the mall were used to create a drawing board for the 3D model in order to designate the locations of the individual components in the scene (Fig. 2). We then printed the photographs of the different components of the scene and determined which measurements were required for individual components. The mall was visited on a second occasion to take precise measurements of these components using a laser distance measurer (Bosch GLR225). The measures were then manually added to each photograph using Adobe Photoshop as shown in Fig. 3.

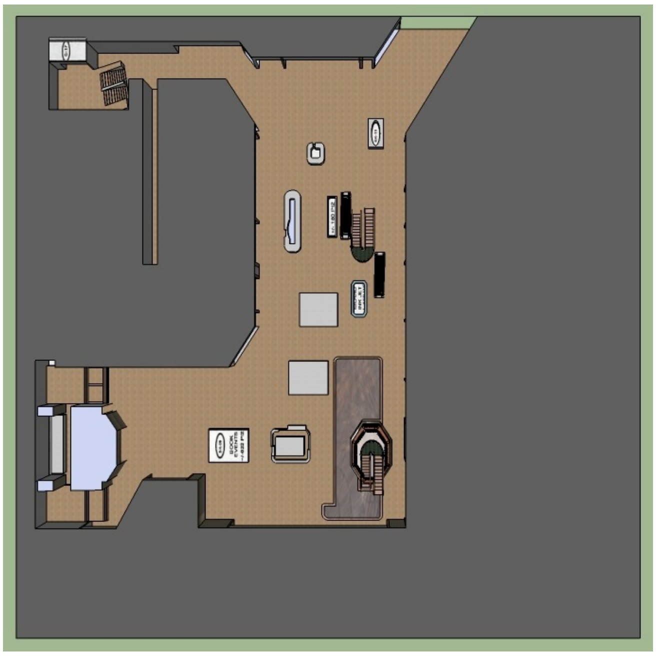

Figure 2. *Top view of Google SketchUp drawing board.*

Figure 3. *Photograph of section of mall with physical measurements added.*

2.2 Creating the 3D model

The measurements and pictures obtained in the first step were then used to model the virtual objects of the scene in Google SketchUp (version Pro 8), as shown in Fig. 4. Google SketchUp was chosen for its simplicity in creating architectural models. Note, however, that it does not give precise control over the number of polygons/vertices of an object during modelling, as compared to other 3D modelling software (e.g., Autodesk 3DS Max, Blender) (Koenig et al. 2011; Koenig 2012). The inability to control the number of vertices while creating an object leads to a reduction in real-time performance of the 3D simulation. Using normal/bump maps and overlaying them onto low polygon models as well as by using appropriate hardware for running 3D simulations can increase real-time performance of the simulation.

The normal/bump maps consisted of multiple texture files created from the original texture which, when used in a game engine, provided a detailed geometry of the underlying object (which in itself did not

necessarily have the corresponding contours). The virtual objects created in SketchUp were then overlaid with the corresponding textures created in Adobe Photoshop.

Figure 4. *Model the virtual objects of a section of the mall via Google SketchUp Pro 8.*

The different objects represented in the model, including benches, kiosks, atrium architecture and staircases, were placed at the exact locations corresponding to those in the real-world scenario, and based on precise measurements (accuracy = ± 5mm). The menus of the food items in the kiosks were extracted from the pictures taken during the initial visit and enhanced using Adobe Photoshop to give a more realistic look. The model also included some components imported from the Google 3D warehouse (e.g. cash register, coffee machine). This was done to evaluate the efficiency of using these generic components in a functional simulation by evaluation of the time required to optimize these components in comparison to the time required for creating similar components in SketchUp.

2.3 Creating the simulation

Models created in SketchUp were then exported to the Unity game engine using the FBX-file format. Note that the no-cost version of SketchUp does not permit exporting the model to FBX file format and hence we used the Pro version. Following the export of the FBX files using the Pro version, the 3D model files were also exported in DAE format (a format available in the no-cost version). The DAE files were then imported to Blender, a freeware and open-source graphics software capable of 3D modelling and creating game simulations. Blender allows the model to be exported in FBX file format which can then be used in Unity for designing simulations. We explored both types of model export solutions in order to determine whether using Blender could make the workflow more cost effective.

Unity (Version 3.5) is an integrated development environment consisting of both an editor to develop/design games and a game engine for executing the final simulation. It was chosen based on the study by Koenig et al. (2011) which found it to be the most cost-effective engine in comparison to other game engines in terms of rapid prototyping and the availability of a fast asset pipeline leading to quick import of 3D models, textures and sounds. In addition, games developed using Unity can be deployed on both Windows and Mac operating systems giving researchers and clinicians the ability to use a computer of their choice. Unity has both no-cost and pro versions; we tested both versions to determine whether most of the required functionality could be fulfilled using the no-cost version.

Unity's editor is user friendly and features a simple drag-and-drop interface for inserting virtual objects as well as for assigning functionality to objects within the simulation (e.g., mesh collision). This is an important factor in rapid prototyping as the software should allow quick configuration of simulation tasks within a VE. The individual functions which define interactions between the user and different virtual objects as well as data collection were programmed using custom code written in Javascript as well as C#. Lighting was modified within Unity using the beast lightmapping tool which bakes light maps with advanced global illumination to simulate a real-world, life-like experience of the shopping mall environment as shown in the Fig. 5. The VE, along with the programmed tasks, were then published as a stand-alone application which can run on Windows and Mac operating systems.

Figure 5. *Rendition of simulated section of mall published as a stand-alone application.*

3. RESULTS

The current study describes a detailed workflow of the approach taken to create a realistic, accurately scaled model of a complex real world environment. The development process was demonstrated by creating a 3D model of an enclosed section of a shopping mall. The resulting VE appears to be realistic and the details of the individual components appear to correspond closely to their real world counterparts. A series of user-tests of these factors is planned. The development of the complex VE took several days to complete, for a total of ~ 500 hours, due to software limitations as well as relative inexperience with the potential software solutions presented in the study. We estimate that a developer or a person with technical background could do a similar task in ~ 500 hours (~200 hours for 3D modelling, ~ 100 hours for integrating all components in Unity such as 3D models, lighting, sound etc, ~ 50 hours for scripting and ~ 150 hours for debugging and deploying the final simulation).

3.1 3D virtual model

The virtual environment (Fig. 6, right panels: Top – SketchUp, Bottom - Unity) created in SketchUp and Unity closely resembled the real environment (Fig. 6, left panel). The complex VE seems to provide detailed visual information in terms of geometry and real-life textures which may enable the participant to easily recognize and relate to the environment.

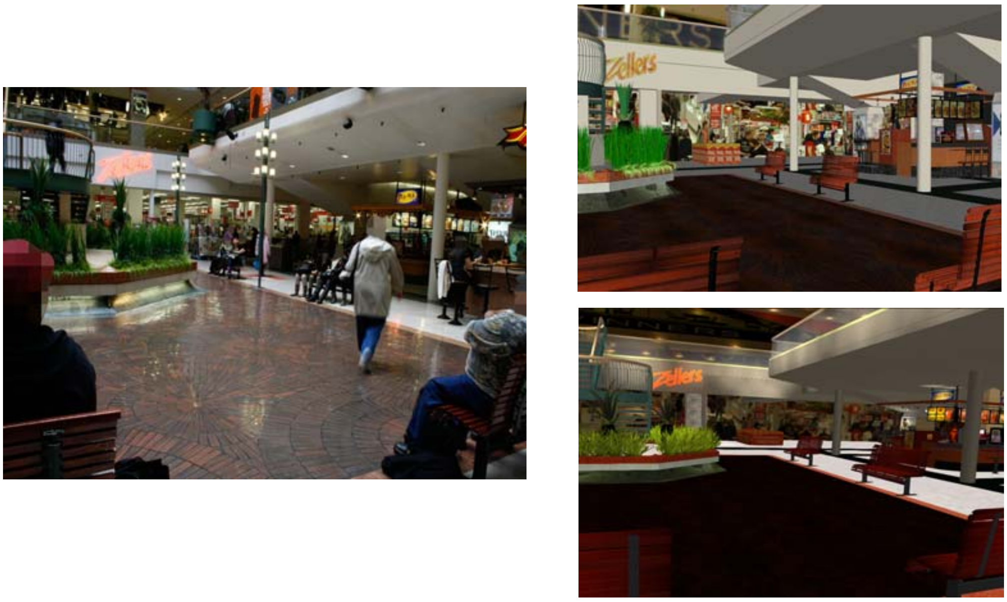

Figure 6. *The virtual environment (right panels; top-SketchUp, bottom-Unity) closely resembled the real environment (left panel).*

Google SketchUp provided a very user-friendly and easy interface to quickly prototype context-specific, complex 3D models. The software provides several built-in tools for creating various architectural models which are easy to understand and implement. In addition, users can install additional libraries of tools made available at no cost by other SketchUp users.

During the development process, when exporting 3D models into game engines like Unity, one has to make sure that the faces of the individual components (each 3D component consists of several polygons having 2 faces, front and back) of the VE face forward since they otherwise disappear as Unity does not render the back portion of a face (unless both front and back faces are exported, which ultimately deteriorates the performance of the real-time simulation). We also found that exporting the 3D model using SketchUp Pro and Blender resulted in similar FBX files which could be used in Unity. However care should be taken when exporting models with these two different methods, especially in terms of the units of measurement (inches, feet etc.) and application of textures to their corresponding components.

One of the primary concerns with SketchUp was the updating of the original 3D model. In cases where changes needed to be made to the 3D model (e.g., changing the structure of the kiosk), the process became complex and time consuming as it necessitated a full re-export of the model from SketchUp and re-import to Unity. We found that using Autodesk 3DS Max or Maya may help address this concern since they export a 3D model file (.3ds or .mb) to be used with Unity. Thus, subsequent changes can be made to the exported model files that are then updated in real-time within Unity. However, it is important to note that non-professional users may find the advanced software (e.g., Autodesk 3DS Max) time consuming and difficult to use. Based on our experience, we suggest that Google SketchUp be used to design environments which do not need extensive updating once created, while the advanced software mentioned above should be used for designing large-scale, complex environments which need frequent updating.

Google 3D warehouse, a no-cost virtual 3D component store, provides a large array of components that can be imported and used in the VE. We found that importing such components was useful for quickly adding common objects such as coffee machines and cash registers to the 3D model. However, care should be taken when adding components from the warehouse as they may have properties such as high polygon count, etc. that may decrease the overall performance of the resulting game simulation. A solution to this problem would be to import the model and then optimize it, however the time required for such optimization may not necessarily offset the time required to build the same component in SketchUp. We thus suggest exploring the different components in the warehouse and utilizing only those which meet the specific requirements of the model.

3.2 Developing simulation tasks

A first person controller was placed in the model along with virtual cameras to capture both a “first person” viewpoint as well as a “birds-eye” viewpoint. A small map, which shows the virtual camera output from the “birds-eye” viewpoint, was overlaid onto a rectangular portion at the lower, right edge of the screen to inform users of their real-time position as well as the concurrent position of the task target. The display of the map was made optional and the map appeared or disappeared on the screen by toggling the “M” key.

We defined four starting locations and two locations for final destinations within the shopping mall model. Since the model was created to scale, each location and the traversed route is saved as a vector in 3D space and angles and distances are calculated from the position data. In addition, time spent while performing different tasks and a video recording of the “first person” camera viewpoint is saved and analyzed to investigate the different strategies used while navigating the VE. We also created another floor in this section of the mall, shown in Fig. 7, for training users on the input device and giving them an opportunity to view the VE prior to the actual task. This helps users to adapt to navigating within the VE with a given interactive device (e.g., joystick). The feedback obtained from the user can then be used to set up the primary simulation tasks as well as the parameters of the interactive device.

Navigation by the user is accomplished by either keyboard/mouse combination, mouse alone or a joystick. For this study, we use the Saitek x52 Joystick control system which has multiple programmable buttons along with a handle that twists to provide rotation in the horizontal plane. The rotation aspect is particularly important for this simulation since navigation through a complex VE requires users to turn and orient their gaze to the target before proceeding towards it. The joystick is programmed so that users can observe the surrounding environment while remaining stationary in one position and then steer forward/backward by titling the joystick along an x-y axis which propels them along the desired path. Preliminary work with the simulation suggests that the joystick may present a more intuitive interface for navigation in comparison with a mouse or the keyboard/mouse combination. We also made several tests of

the Microsoft Kinect sensor, using gesture recognition to interact within the VE. This appears to be a viable device which may be easier to operate than a joystick, especially for people with disabilities.

We tested both versions of Unity (no-cost and Pro ($1500 US) and found that the no-cost version has sufficient features for importing models and creating the desired simulation tasks. However the resulting simulation may have jagged edges due to aliasing, making it somewhat more difficult for the user to focus within the VE. The Pro version provides an anti-aliasing image filter that creates smooth edges as shown in Fig. 7. The Pro version also provides additional tools which can be used while designing the simulation as well as those that can be implemented during run-time. For additional information regarding the two versions of Unity please refer to Koenig (2012) which provides detailed information regarding the pros and cons of the two versions. We would suggest using Unity Pro for its advanced set of features.

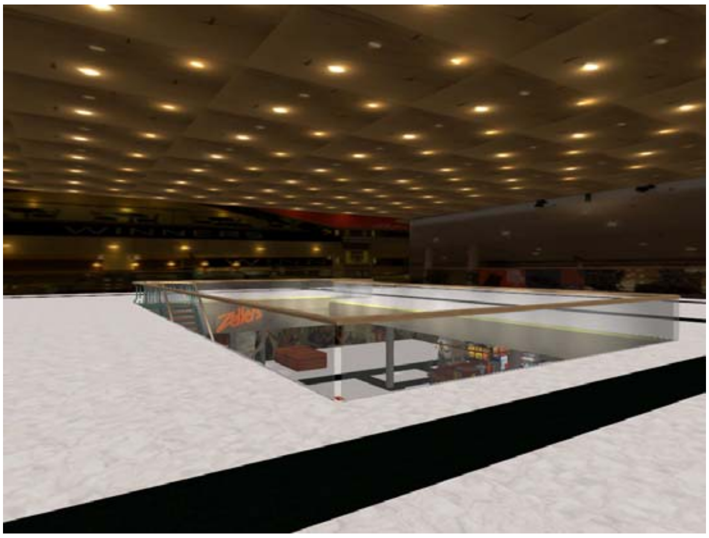

Figure 7. *Section of the shopping mall used to enable practice of navigation and familiarity with simulated scenes.*

4. CONCLUSIONS

The results of this study demonstrate the detailed workflow involved in creating context-specific, complex 3D VEs that provide realistic, scaled models for training clients to perform cognitive and navigational tasks. While cost-effective development of similar VEs has been demonstrated in the past (Koenig et al. 2011; Koenig 2012), this project specifically addressed the simulation of a very large-scale, complex VE. Such complex environments may be created in approximately 500 hours by a single developer. Note that this time would be significantly reduced for subsequent iterations of development of the same VE and also as the developer's becomes more familiar with the development tools. Using a systematic and cost-effective workflow to create such a complex environment may provide clinicians and researchers with a simple yet dynamic, context-specific rehabilitation assessment and evaluation tool. Future development will include collecting and comparing data (e.g. task completion time, navigation route etc.) in the real and simulated environments, and to continue to explore tools that will have even greater usability.

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Collaborative virtual environment for conducting design sessions with students with autism spectrum conditions

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ABSTRACT

Young students with autism spectrum conditions (ASC) often find it difficult to communicate with others face-to-face. Virtual reality offers a platform in which students can communicate in a safe and predictable environment where face-to-face communication is not necessary. Participatory design with end-users is an important part of developing successful, usable and enjoyable technology. As designers of technology for young students with ASC, we seek to involve these end-users in the design of software. Therefore, we have developed the Island of Ideas: a collaborative virtual environment (CVE) designed to facilitate participatory design activities with students with ASC. In this paper we report an experimental trial of the Island of Ideas CVE as a meeting space in which a researcher talks with students to find out their views on computer game design and their ideas for new game levels.

1. INTRODUCTION

Involving users in the design of technology through participatory and user-centred design (UCD) methodologies is widely acknowledged as an important step in developing appropriate and usable programs (Lewis, 2006). Traditionally, the involvement of users in the design and development process of technology intended for use in an educational context, has focused on adult users (Scaife and Rogers, 1998). However, over the past 20 years, this process has gradually moved away from seeking this information from proxies such as parents or teachers only, towards obtaining additional information directly from the children themselves (Read and MacFarlane, 2006; Borgers and Hox, 2001; Borgers et al., 2000). There has been a marked increase in research that has involved child end-users in design (e.g. Garzotto, 2008; Hall et al., 2006; Druin and Fast, 2002; Druin, 1999; Bekker et al., 2003). Most researchers now acknowledge the importance of consulting children on technology design as they often have different capabilities and experiences with technology and therefore different requirements (Bekker et al., 2003). Children have been involved in the design process through many different types of UCD activities (e.g. prototype testing activities, workshops, evaluation questionnaires) and through various roles such as user, tester, informant and design partner (Druin, 2002).

The use of technology for supporting and engaging children with autism spectrum conditions has been shown to be effective (Hardy et al., 2002; Barry and Pitt, 2006; Hart, 2005; Battocchi et al., 2008; Moore and Calvert, 2000) and software that has been developed specifically for this user group is on the increase (Williams et al., 2002). However, despite the increasing involvement of children in technology design, the number of cases where children with special needs, and in particular, autism, have been involved are relatively small (Parsons et al., 2002; Benton et al., 2011) and adult proxies (e.g. see Kientz et al., 2007; Leo and Leroy, 2008; Hirano et al., 2010; Falcão and Price, 2010) or their typically developing (TD) peers (e.g. Garzotto and Gonella, 2011) are usually involved instead.

Encouragingly, users with special needs and autism are becoming more involved in technology design projects (Guha et al., 2008; Benton et al., 2011). However, when children with autism are involved in design, their role is usually limited to that of a tester, where they are observed whilst trying out an already existing prototype (Guha et al., 2008). Researchers and teachers observed children with autism in their exploration of

prototypes to inform the design of the ReacTickles software suite (Keay-Bright, 2007). Similarly, Madsen et al. (2009) reported conducting participatory design sessions with seven adolescents (aged 10 to 17 years) with ASC by observing their interactions with a prototype. Millen et al. (2011) developed and tested a 'design a game' method that was adapted to meet the needs of children with ASC through a structured process that was supported with visual aids and prompts. Benton et al. (2011) also tested an adapted participatory design method for generating ideas with children with autism for a mathematics program.

Researchers are faced with a number of challenges to overcome when seeking to involving children with autism in the design process. Children with autism may find communicating their views and opinions difficult, they may have limited imagination skills and they may have difficulties in understanding another person's viewpoint (Millen et al., 2011). Additionally, they may require more time to understand, accept and adapt to changes (Kärnä et al., 2010) and have limited motivation and a fear of failure (Francis et al., 2009). Children with autism are therefore less likely to be involved in the design process due to these perceived challenges; those authors that do report involving children with special needs in design tend to provide little detail and guidance about the methods used (Frauenberger et al., 2011). The result is that there is very little in the way of recommended methods or guidelines for involving this user group (Parsons et al., 2011; Benton et al., 2011).

Due to the specific needs of children with autism, an adapted or "special" approach is required when seeking to involve this user group (Leo and Leroy, 2008). This is something we have been exploring through our work in the COSPATIAL project (see Millen et al., 2011; Parsons et al., 2011) in which we developed CVEs for supporting students in developing social competence and collaboration skills. In COSPATIAL, CVEs were chosen because they offer a way for students with ASC to communicate without the need for face-to-face communication which they may find difficult (Parsons et al., 2011). This feature combined with the other attractive features of computer technology for children with ASC, motivated us to explore the potential of CVEs for supporting participatory design activities with this user group. To test this idea, we developed the Island of Ideas CVE.

2. THE ISLAND OF IDEAS CVE

The Island of Ideas CVE was built using GLU4D technology (an audio-video communication CVE developed at the Mixed Reality Lab, University of Nottingham) and allows users to communicate with each other on a virtual island (Figure 1). It has been designed as a virtual meeting space in which a researcher conducts a participatory design session with children to find out their views on computer game design.

Figure 1 (left). *The Island of Ideas CVE.* **Figure 2 (right).** *A student and researcher accessing the CVE from separate laptops (Images blurred to protect student identity).*

A child and researcher can enter the virtual room from separate laptops and communicate with each other via a headset (Figure 2). The users can be represented by either a computer-generated avatar or via "video pods" (Figure 3). Prior to entering the virtual environment, the student is able to choose from a selection of male and female avatars with different coloured hair and t-shirts. The video is a form of video-mediated communication that allows users to view other participants in real-time. Video streaming technology allows the application to capture and distribute a live webcam feed that can then be displayed on the recipient's pod.

Within the virtual environment there are numbered stations from 1 to 5 positioned clockwise around the island. Different activities or discussions related to game design are carried out at each station. The stations allow the researcher to structure the session in a clear and logical way that help to support the student's understanding throughout the activity. The student has free movement around the virtual space but is asked to move around the island from station to station with the researcher. Each station usually hosts three boards: a

start board that explains the activity that will be conducted at that station, an activity board where the activity is carried out and an end board that summarises the activity and instructs the user to continue to the next station. These start and end boards correspond to a virtual timetable that is displayed at the first station on the island and further structure the activity and help students recognise what is required from them in each section of the session.

Figure 3. *Representation within the CVE: avatars (left) and video pods (right). (Images blurred to protect student identity).*

3. EVALUATION

A school-based study was conducted to evaluate the Island of Ideas as a computer-mediated, participatory design resource. The study also examined the influence of avatar representation for supporting students with ASC in reviewing the design of computer games and generating ideas for a new level for the game. The differences between the two types of representation in the CVE posed interesting issues: on the one hand, being able to actually see the student via a webcam may help the researcher to mediate the session and monitor the student's interest and motivation levels and the novelty of the video pods may be rewarding for the student; on the other hand, however, the student may feel more comfortable and safe when their actual appearance is shielded from the researcher and the pressures of non-verbal communication are removed altogether (Benford and Standen, 2009). It was therefore expected that students would prefer to use the CVE with avatars rather than video-pods.

Twelve students with an autism spectrum condition or Asperger's Syndrome (age range: 11-14 years; 1 female, 11 male) participated in the evaluation study. All of the students had verbal ability and attended a mainstream school in which they received special support for the impairments associated with their autism which were primarily associated with behaviour, social interaction, communication, imagination and rigidity of thought processes. Each student participated in four 60-minute sessions, one a week for four weeks. The first session was an introductory session in which the researcher introduced herself and the project by completing worksheets with the student. The following two sessions involved the student using the Island of Ideas and engaging in the following activities at the virtual stations:

- *1) Playing a commercially available computer game;*
- *2) Interview discussion with the researcher, answering questions about design features of the game just played;*
- *3) Drawing ideas for a new level for the game.*

During the sessions, the researcher and student entered the virtual environment from separate laptops and communicated using headphones and microphones. For each session a different game was reviewed and the interview was conducted under one of the study conditions (in counterbalanced order), as follows:

- *Experimental condition 1. Island of Ideas CVE with avatars: Participants are represented by computer-generated characters or avatars.*

- *Experimental condition 2. Island of Ideas CVE with video pods: Participants are presented through live video streaming and can see each other directly within the virtual environment via a video pod screen.*

Activities or discussions were carried out at each station as follows:

Station 1. Introduction to session: a visual timetable was displayed and the researcher explained the aims of the session to the student. This helped to facilitate the student in understanding what they would be doing and what was expected of them. A photograph of the student's avatar or video pod (see Figure 3) was taken within the CVE and displayed at this station so that the island became their personal Island of Ideas.

Station 2. Playing the game: a web browser on the island allowed the student to play one of two commercially available games that they would subsequently review. The student was asked to try out the game as many times as they wished in a ten minute period. They were asked to think about what they liked, disliked and wanted to change about the game during the period of game play.

Station 3. Describing the game: the student was asked to explain to the researcher what the game was about using a screenshot from the game to remind them. This board served as an introduction to the next activity.

Station 4.a) Reviewing the game: again, screenshots from the game were used to prompt the student to talk about various aspects of the game and how they could improve them (e.g. rewards, characters). The student (or researcher if the student preferred) could type their ideas on to a text board next to the screenshots.

Station 4.b) Ideas for a new level: it is also at this station where the student and researcher developed ideas for a new level for the game. They were able to draw their ideas using a paint program on the island and a drawing tablet and pen attached to the laptop. The researcher also had a tablet and pen and could draw on behalf of the student if they preferred or if they were particularly struggling.

Station 5. My ideas gallery: the typed and drawn ideas that the student created were displayed on five boards at the ideas gallery. This tool was used to alert the student to the completion of a section of work or to show them their work had been displayed and was therefore valued. The student and researcher reviewed the ideas together and the session was concluded.

The fourth and final session was an evaluation session where the students were asked to critically review the Island of Ideas with the researcher.

4. RESULTS

To understand the usefulness of the Island of Ideas CVE as a tool for supporting participatory design sessions we examined the outputs generated by the children (i.e. whether they were able to generate game ideas) and collected the children's opinions of the task, the virtual environment and character representation format. These are reported in the following sections.

4.1 Use of the Island of Ideas for participatory design activities

All 12 students completed both sessions (using experimental condition 1 and experimental condition 2 each for one-hour a week apart) and stayed motivated throughout the sessions. This in itself was a positive result as nearly all of the students were described by their teachers as students who find it difficult to concentrate and focus and are easily distracted. This was the first time (apart from a practice session) that the students had used a tablet and graphics pen and they all seemed to find this interesting and exciting to use. At first, some of the students were reluctant to draw as they were concerned that they did not have adequate drawing skills but, as the researcher demonstrated that this did not matter and it was simple to erase parts of the drawing, all of the students were encouraged to join in (see Figure 5 for examples of student drawings). Teachers had commented that a number of the students had poor motor skills, did not like drawing or had "no imagination" and therefore it was encouraging that they did all produce drawings. This may indicate that the virtual surroundings of the CVE can inspire or encourage students' imaginative side or that using the graphics tablet was sufficiently novel and exciting that they overcame their reluctance.

In previous participatory design sessions with typically developing students and students with ASC (Millen et al, 2011) struggled to generate ideas for a completely new game and even though the activity was heavily structured with worksheets and introductory activities for the children with ASC, this task still proved extremely difficult. For this reason, the children with ASC in this study were asked to generate ideas

for a new level for two existing games (one game in each session) rather than a completely new game altogether. The students responded well to the drawing activity and demonstrated that they were able to use the structure of the existing game that they had played to generate new content and ideas for the game. One of the existing games involved successfully moving a character from one side of a river to another to collect rewards by jumping from log to log (Figure 4). Using this idea as a template, students generated ideas for new levels for this game such as navigating a character from one planet to another to collect aliens or getting from one side of a sinking sand river to another by using moving cacti as platforms (Figure 5). Students were able to generate a range of ideas for new level environments, obstacles, rewards and ideas for the representation of lives.

Figure 4. *Screenshot from one of the games that the students developed new level ideas for during the session* (*http://www.bbc.co.uk/cbbc/games/way-of-the-warrior-game*).

Figure 5. *Examples of student drawings of game ideas within the CVE.*

Being able to see and review the ideas that they had generated with the researcher at the ideas gallery was motivating for the students and allowed the researcher to ask the student to reflect on their ideas and explain them again. This often generated a clearer explanation of why they had added an idea or object to their drawing as they were no longer focused on the drawing task itself.

4.2 *Questionnaire results: student preferences*

The students completed a short questionnaire at the end of each session. The researcher read the questions to the student and asked the children to think about how they felt about using the virtual island with different forms of representation: avatars and video pods. The students' responses were recorded on a "smiley-style" likert scale (Figure 6) from 1 ("Not at all") to 5 ("Very much"). Each question and the results obtained are shown below.

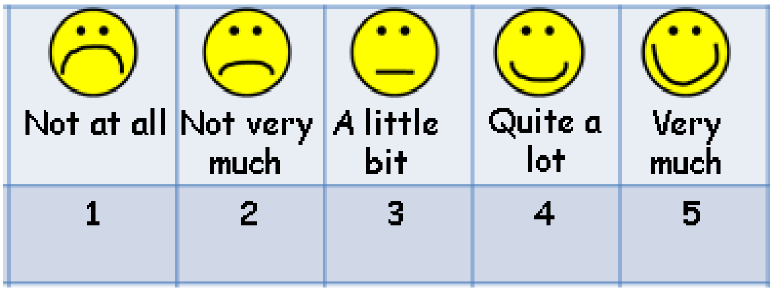

Figure 6. S*miley likert scale (adapted from Read and Macfarlane, 2006).*

Q1: Did you like using the avatars / video pods on the virtual island to talk to the researcher about game design today?

This question was asked separately for avatars and video pods at the end of the corresponding session. The results show that the median rating for the avatar condition was 4 (IQR = 1.75) and the median rating for the video pod condition was 5 (IQR = 0.75). This indicates that there was a slight preference for the video pod representation over the avatar representation when the sessions were rated in isolation.

Q2: A) *Did you like using the* ***avatars*** *on the virtual island to talk to the researcher about game design in week* ***1****?* B) *Did you like using the* **video pods** *on the virtual island to talk to the researcher about game design in week* ***2****?*

The student was asked these two questions together after completing the both of the CVE sessions and, again, their responses were recorded separately for each mode of representation on the smiley scale (Figure 6). The median score was 4 for both the avatar and video pod condition with the interquartile range for avatar being 2 and 1.5 for video pod. The ratings for each mode were similar with very few students commenting negatively on their experience of using the CVE. Only one student gave a negative rating for the avatar condition (they had reported feeling tired on the day and so this may have affected their opinion).

Q3: Did you prefer talking to the researcher about the game you played in week 1 using the virtual island and the video pods to talk to each other or in week 2, using the virtual island and the avatars to talk to each other?

The students were also asked to indicate which mode or representation they preferred overall after experiencing both conditions. Figure 7 shows the format of this question presented to students who experience the CVE using the video pod in week 1 and avatars in week 2 The results showed that 5/12 students stated that they preferred using the CVE with the avatars and 7/12 students preferred using the CVE with the video pods.

The outcomes of the study suggest that the Island of Ideas shows potential as a tool for supporting PD with children with ASC as all children were enthusiastic and motivated during the sessions. Initial results suggest that there is a slight preference for using video pods when students with ASC participate in participatory design sessions on the virtual island.

4.3 *Student review of the CVE*

The review session lasted one hour and was structured by the researcher with a timetable and pre-prepared worksheets as these help the student to focus. The session focused first on the differences between video pods and avatars and what the student thought of each one and how they would improve them (Figure 8- left). Next, the student and researcher progressed on to a worksheet where the researcher talked with the student about their opinions of the Island of Ideas and how they would improve the Island (Figure 8 – right).

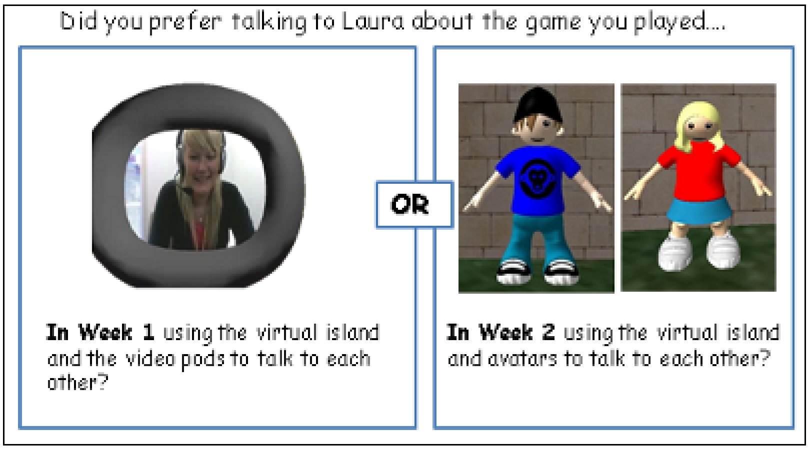

Figure 7. *Format of question for overall preference (question 3).*

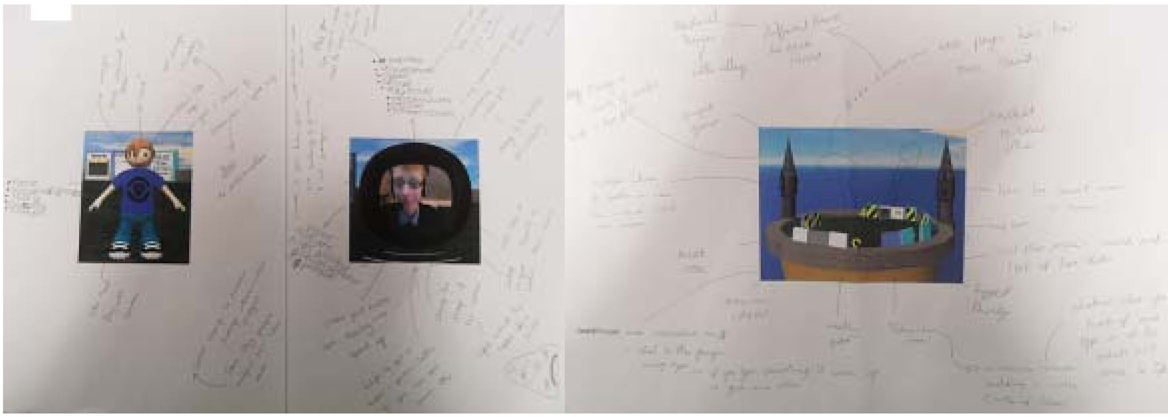

Figure 8. *Evaluating avatars worksheet (left) and evaluating the Island of Ideas worksheet (right)*

Table 1. *Examples of comments from students during the evaluation session.*

Avatars	Video pods	The Island of ideas
"I preferred this one because you can choose the clothes"	"Useful because it shows your face and expressions"	"Should be able to go somewhere – sail to another islands"
"Not enough variety"	"It looks cool!"	"Play more games from a game list to get inspiration"
"Should be able to customise"	"You know who you are talking to"	"Choose from a list of backgrounds: Castle Island, Grand Canyon Island, Cruise ship"
"The mouth, arms and eyes should move when you're talking"	"Video pods are better because you can see the person"	"Customise the island – add objects, trees, plants".
"Liked being able to choose the colour of the [avatar's] top"	"Some shy people might not like the pods"	
"I preferred this one because I could mess about without [the researcher] seeing"	"Easier to know what we're doing and how we're feeling"	
	"More like real life"	

Table 1 shows some examples of student ideas for improving each feature. Most of the students thought that they should be able to customise the video pods in some way e.g. changing the colour, adding patterns, adding their name to the pod. Although the students were able to choose the hair colour and t-shirt of their avatar, most students felt that this level of customisation was not enough and that they should be able to customise the avatar by choosing its hair colour, clothes and facial features. Some students suggested combining the avatars with the video pods by creating an avatar that also had on it a video port e.g. on the head of the avatar. Common suggestions for improving the virtual island were: allow travel to other virtual

islands, include more characters on the island, and allow users to explore the virtual towers and customise the appearance of the island.

5. CONCLUSIONS

The use of computer-mediated participatory design sessions for engaging with students with ASC shows some potential. The students enjoyed using the technology and seemed to find the Island of Ideas exciting and motivating. All students participated in the full one-hour sessions and generated game ideas and drawings. This is particularly important as all of these students were described by their teachers as having difficulties with lack of imagination, motivation and difficulties with attention that are common amongst students with ASC. This is very encouraging and suggests that the Island of Ideas is a beneficial environment for these types of activities. Only slight differences were observed in student preference between the two types of representations within the CVE; 5 preferred to use the CVE with avatar and 7 preferred the video-pod. This result is extremely interesting as it was considered that the video-mediated condition may be less popular with ASC children. In a study of the opinions and attitudes of adults with high functioning autism or Asperger's Syndrome (AS) towards internet communication, Benford and Standen (2009) found that people with autism favoured text-based internet communication (e.g. emails and chat rooms). It was suggested that the reason for this was removal of the stressful nature of face-to-face interactions. According to Benford and Standen (2009), a rise in video-mediated types of communication in the future may diminish the positive features of computer mediated interactions for users with ASC. However, the findings from the current study and other recent studies that have found positive responses from children and adolescents with ASC and AS (e.g. Baker and Krout, 2009) suggest that the younger autism generation may be more accepting of computer-mediated video communication. However, it could be that the current task and novelty of the CVE were sufficiently motivating for the children who participated in the study to overcome reluctances in video-streamed communication settings. Overall, the study showed that students with ASC can be involved in participatory design activities and can provide ideas, both for development of new software games, and for improvement to computer-mediated environments. All of the students involved in this research put forward ideas for ways in which the CVE and forms of representation could be improved and therefore these should be explored in future work.

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Development of a low-cost virtual reality-based smart glove for rehabilitation

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ABSTRACT

Presented is the third version of a low-cost bimanual rehabilitation system designed for in-home use by post stroke patients to improve hand and upper extremity function. Companion virtual reality software is still in development. The mechanical characterization and healthy subject (n=24) testing of the system sensors is described. These sensors include potentiometer bend sensors for finger motions and inertial measurement units (IMUs) for hand/arm position and orientation. The system accurately measures larger finger angles and all functional ranges of hand orientation (yaw, pitch, roll). Measurement of small finger angles and position of the hand in space requires further refinement.

1. INTRODUCTION

In this paper we describe the development and testing of a prototype low-cost virtual reality-based (VR) glove device designed to meet the needs of millions of people worldwide who are left with weakness in their hand and arm following a stroke (CDC, 1999). In the United States alone, nearly 800,000 people experience a new or recurrent stroke each year (Lloyd-Jones et al, 2010). At six months post stroke, 55-75% of survivors still have impaired function in the arm (Lai et al., 2002), and in cases with initial UE paralysis, complete motor recovery has been reported at <15% of cases (Hendricks et al., 2002). A key component of this poor functional recovery is impaired use of the hand. Although long term rehabilitation has been shown to provide significant functional benefits to patients with stroke (Dobkin, 1995), access to such care in the future may be limited due to cost. In the US, estimated total costs for stroke care are now near $30 billion/year (Dobkin, 1995). A low-cost VR device that is designed to improve hand and arm function, which individuals with stroke could use independently at home or as an adjunct to ongoing rehabilitation, would help to meet the needs of such patients. Potential benefits of this device include the ability to provide a wide variety of motivating environments to encourage repeated practice, and enhancement of motor learning via augmented feedback (Holden, 2005 and Krakauer, 2006).

Devices used to assist hand and upper extremity rehabilitation takes many forms. Oess et al. (2012) fabricated a glove using the same bend sensors as our system and many of the same sensor issues arose. Shefer Eini et al. (2010) used a visual tracking system for wrist range of motion, forgoing any sensors mounted on the subject. Other researchers such as Standen et al. (2010) use a combination of visual infrared tracking and mounted sensors. Another system by Brown et al. (2010) created a target reaching apparatus with and several hand manipulation/discrimination modules that prompted the subject to move by use of custom software. These devices with the exception of Brown et al. are not meant for bimanual rehabilitation and none combine sensors for finger angle as well as orientation and position of the hand.

The purpose of this study was to assess the accuracy of the bend sensors and inertial measurement units (IMUs) used in our recently developed glove system, the ATLAS, and to begin development of the virtual rehabilitation scenes to be used with the system. We first tested the accuracy of the glove sensors in a mechanical set-up. Next, we assessed how well goniometric and distance measures of hand/ finger movements mapped onto the voltage outputs obtained simultaneously from the glove when it was on a human hand, and how this mapping was affected by different hand sizes. These data will be used in the future to develop a calibration algorithm that adjusts system outputs for differences in hand size. This method

would improve the accuracy of mapping a subject's hand movements to the virtual scene, and presumably the overall effectiveness of the virtual training scenes used with the system.

2. METHODS

2.1 ATLAS System Description

Our bimanual glove system, version 3 (Fig. 1) has four components: gloves, IMUs, resting base for hands, and electronics unit. The gloves use potentiometer bend sensors (Flexpoint Sensor Systems, Draper, UT, USA) to measure finger joint angles and are mounted under a flap of fabric on the back of the glove (dorsal aspect of hand). The bend sensors have sleeves that run up the back of the index, middle, and ring finger, and the thumb. The sleeves allow the bend sensors to 'slide' on the fingers to accommodate length changes caused by finger flexion movements. During extension, the sleeves prevent the sensors from buckling upward and away from the fingers. This feature is designed to improve the fidelity of the finger motion monitoring.

Figure 1. *ATLAS bimanual glove system*

The IMUs (Sparkfun, Boulder, CO, USA) are contained within enclosures that mount on the back of the hand and are used to assess hand orientation (yaw, pitch, roll). The resting base for the hands and forearms is designed to standardize start position during training and to re-zero the IMUs before each block of trials, via a Hall Effect sensor. The IMU used in the system has nine degrees of freedom: 3 axis accelerometer, gyroscope, and magnetometer. The IMU contains an Arduino microcontroller that was used to write an algorithm to calculate orientation. We attempted to also measure hand position in space (x,y,z) via the IMUs, but these measures were not sufficiently accurate, and will require an alternate solution. Cables connect the IMU and Glove outputs to the electronics unit.

The electronics unit contains another microcontroller as well as the filtering and amplification circuits needed for the potentiometer bend sensors. The data from the gloves and the IMUs are combined by the electronics unit microcontroller and sent via USB to the computer. The system is powered by the USB connection allowing it to be connected to any powered USB connection on any laptop or desktop computer. The glove is designed to be low enough in cost to be a feasible purchase for patients to use in their homes (~$150/glove).

2.2 Mechanical Testing

Prior to healthy subject testing the ATLAS sensors were tested mechanically using custom designed test beds. The bend sensors were tested over a long duration trial of 60 minutes for signal consistency and tested using a cylindrical test bed to measure voltage output versus bend radius. The IMUs were tested using a two degree of freedom motorized test bed. Trials of the IMUs were run in the range of ±50 and ±75 degree in roll, pitch, and yaw. The mechanical testing was consistent with the results found from the healthy subject testing. For more information see Sivak (2012).

2.3 Human Subject Testing

The study was approved by the Northeastern University Office of Human Subjects Research Protection, and all subjects signed an informed consent prior to their participation. A total of 24 subjects (11 males, 13 females; mean age=25.5±6.9 yr) with a broad range of hand sizes, were tested. Hand tracings (Fig. 2) were obtained from subjects and marked with the following landmarks: styloid processes of the radius and ulnar; heads and bases of the first and fifth metacarpals, metacarpal-phalangeal (MCP), proximal-interphalangeal (PIP) and distal-interphalangeal (DIP) joints of each finger. Using these landmarks, a variety of anthropometric measures were calculated. To assess how well the hand sizes of our sample represented the overall population, we used a hand size calculation method similar to that used by the US Army, so our values could be compared to those of their large (n=3782) anthropomorphic database (Gordon, 1989). Length was measured from tip of the middle finger to the center point between styloid processes and width was measured from the fifth MCP to the second MCP (Figure 2, red dotted line). For our sample, mean width was 9.4 ±0.5 cm and length was 20.2±0.5 cm for males; for females, mean width was 8.4 ±0.5 cm and length 18.1 ±1.1 cm. In terms of percentiles, our female subjects hand size values ranged from the 5th to the 99th percentile of the army sample; males ranged from the 35th to 99th percentile of the army sample. Although smaller hand size for males was not represented in our sample, smaller hand size in general was represented by the female subjects. Because of this percentile distribution, our sample, though small, appears to be a fair representation of overall population hand size. Figure 3, below, shows the hand size distribution for our sample.

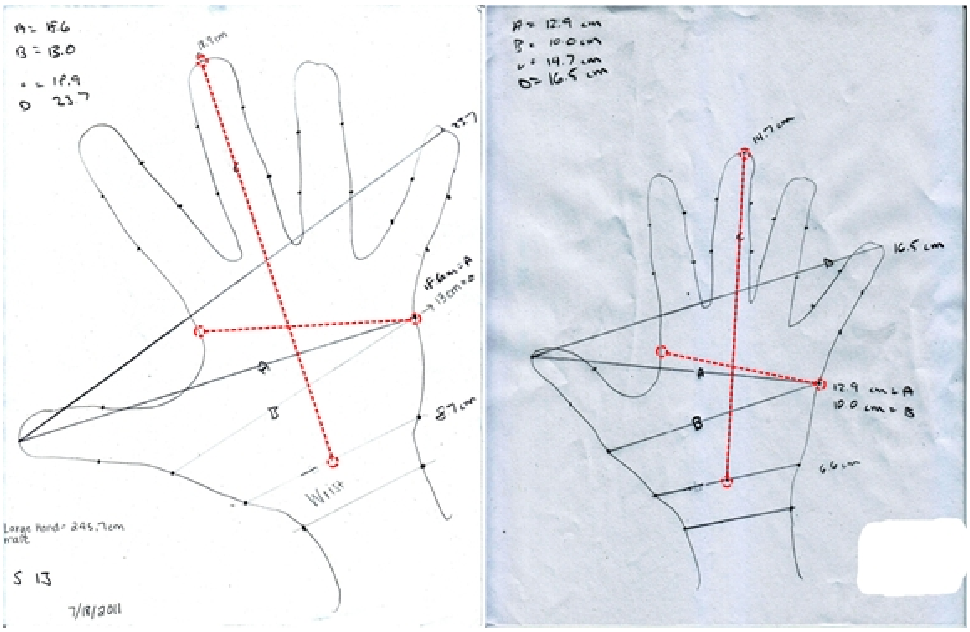

Figure 2. *Two subject's right hand tracings.*

2.4 Procedure

Testing of each subject was done in a single session of approximately two hours. After hand tracings (Fig. 2) were obtained, subjects donned the right or left glove and underwent one of two protocols, presented below.

2.4.1 Bend Sensor Protocol. This test consisted of placing each subject's hand on a series of templates for static angle measurements. Each of these templates was designed to place the subject's fingers in a desired position at which time measurements of the metacarpophalangeal (MCP) and proximal interphalangeal (PIP) joints were taken for the thumb, first, middle and ring fingers using a manual goniometer (Fig. 4). After the

goniometer measurements were collected, the subject was asked to maintain the position for five seconds while the bend sensor voltage was recorded.

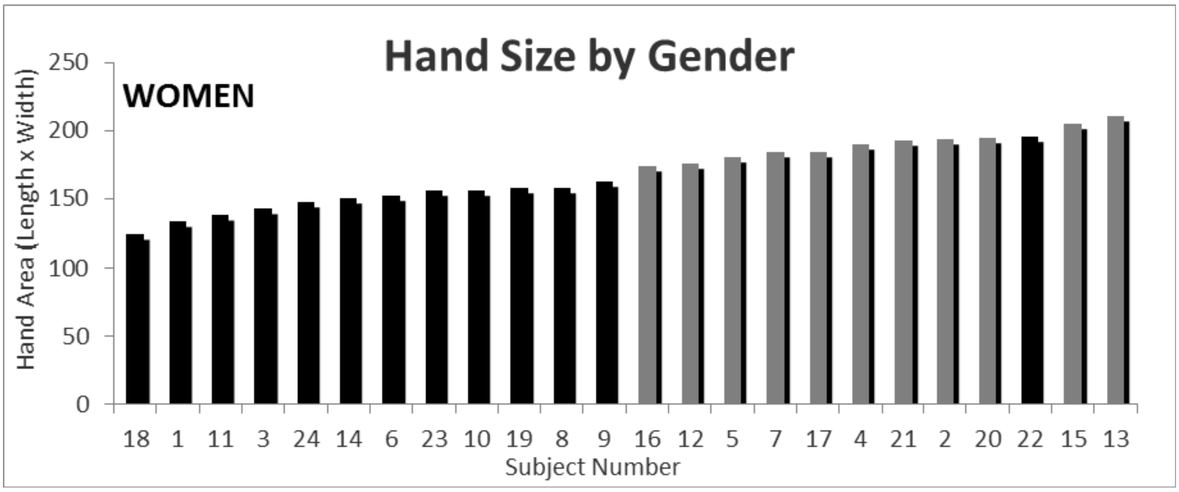

Figure 3. *Chart of hand size by gender*

Figure 4. *Examples of positioning templates and goniometric measurement*

For the bend sensor protocol, these measures were taken on the right hands of all subjects (n=24), and on both the left and right hands for n=12 subjects. The list of tests performed is below.

1. Baseline: all joints fingers and thumb at full extension (0° or 180° on the goniometer)
2. 45° MCP: all fingers at 45° template for MCP Flexion
3. 45° PIP: all fingers at 45° on template for PIP Flexion
4. 90° MCP: all fingers at 90 degrees on template for MCP flexion
5. 90° PIP: all fingers at 90 degrees on template for PIP flexion
6. Max Thumb MCP: instruct subject to flex thumb maximally at MCP, the goal is isolated MCP (subject may use passive motion to obtain maximal flexion)
7. Max Thumb IP: instruct subject to flex thumb maximally at IP, the goal is isolated IP
8. Max Thumb MCP/IP: instruct subject to flex thumb maximally at MCP and IP
9. Thumb 45° MCP / 45° IP: thumb MCP and IP at 45 degrees flexion
10. Thumb-small finger: thumb opposition to pinkie fingertip
11. Thumb-index: Thumb opposition to index fingertip
12. Max MCP / IP: instruct subject to passively flex thumb maximally in IP and MCP
13. 90° MCP / 90° PIP: place subject on the template device so that PIP and MCP of digits 1-3 are at 90°. Have this done with forearm in the vertical position.
14. 45° MCP / 45° PIP: place subjects hand on the appropriate template so that PIP and MCP of digits 1-3 are at 45°. This will also be done with forearm in the vertical position.
15. Dynamic open-close hand: Instruct subject to open and close hand fully for five seconds. The subject should start with the hand in a comfortable fist, all joints will then be measured before opening of the hand begins. The subject will then open and close their fist for five seconds. Movements are timed with computerized metronome, @ 1 Hz.

2.4.2 IMU Protocol. This test looked at the device's ability to measure hand orientation and position in space (n=12). First, subjects completed the bend sensor protocol using the right hand. Then, they completed the IMU hand in space protocol using the same (R) hand and arm. This consisted of moving the wrist and/or forearm/arm in six different ways: roll (supination/pronation), pitch (wrist extension/flexion), yaw (radial/ulnar deviation), medial-lateral (x), forward-backward (y), and up-down movements (z). The subject was asked to move through a distance of ±30cm for 5 seconds, hold the end position for one second, and return a total of five times for each test. Again, movements were timed using a computerized metronome. The list of tests is below.

1. Roll: Subject used a template to rotate forearm from pronation to supination and back (~180°)
2. Pitch: Subject used arm rest and template to facilitate wrist flexion and extension (full excursion)
3. Yaw: Subject performed radial and ulnar deviation on top of a guide (full excursion)
4. Side to side: Subject slid their hand from left to right 60cm
5. Forward-backward: Subject slid their hand forward and back 60cm
6. Up-Down: Subject slid their hand against a vertical guide for 60cm of movement

2.5 Virtual Scene Design

We planned a scene design that would allow us to test a new concept, that of direct or indirect mapping. For direct mapping, virtual scenes would be created which realistically mimicked subject movements in the real world by showing a virtual hand moving on the screen in concert with the subject's movements. For indirect mapping the subject's actual movement in real world would be mapped onto an avatar that could perform different movements. The advantage of direct mapping is that the visual feedback from the VR will be more accurate and understandable to the subject, and make it easier to correct mistakes, potentially enhancing motor learning. On the other hand, indirect mapping allows for more complex and interesting scenarios that may enhance fun and motivation. These factors may also enhance motor learning. We plan to test which of these approaches to virtual mapping is more effective.

3. RESULTS AND ANALYSIS

3.1 Bend Sensor Analysis

The bend sensor protocol was performed on the right hand of all 24 subjects and left hand of 12 subjects. For 0°, 45°, 90°, the targeted joint was positioned at that value while the other finger joints were positioned as close to 0° as possible. For the combination tests, 45°/45° and 90°/90°, MCP and PIP joints were simultaneously positioned at the same angle. Figure 5 below displays the data for the goniometric measures versus the test template for all the 45° and 90° tests.

Overall, the desired positions, especially at 45°, were achieved with good accuracy, but there was some variation due to differences in subjects' hand size, finger length, slope of MCP joints relative to the horizontal and other anthropometric factors. The 90^o positions were limited as well by the glove itself plus the liner glove which was worn for cleanliness. Therefore, we use the actual measured goniometric values for each joint to test the correlation with the voltage values at each static position tested.

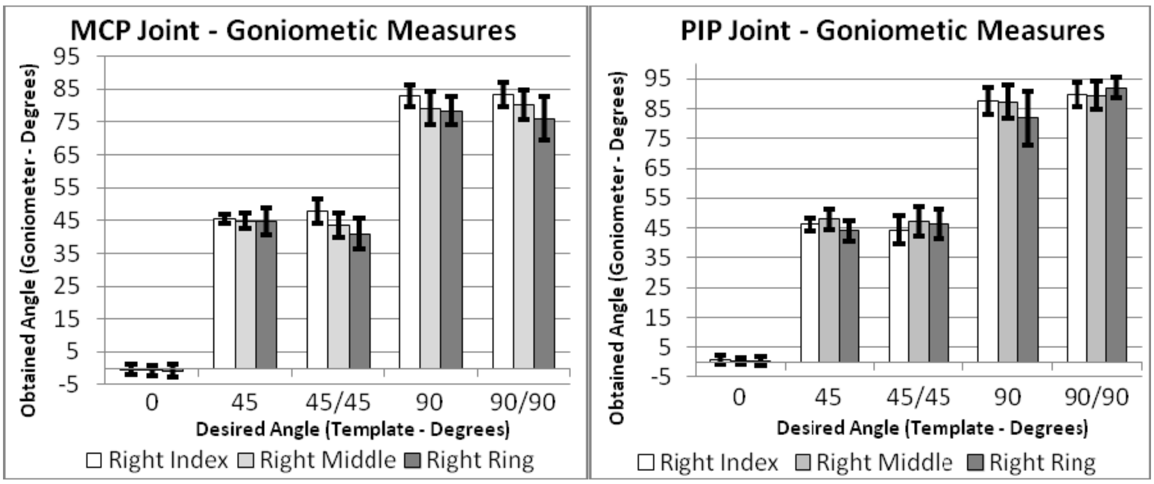

Figure 5. *Charts of goniometric measures vs. test template*

The amplification and filtering circuit of the potentiometer bend sensors creates an exponential output. After characterization testing of the sensors the circuit was created and the results of the characterization match the results found in the chart above. However, during the human subject testing it was found that the response of the sensor at low angles was too low. This is due to the minimum voltage being read by the microcontroller and has since been fixed by increasing the initial resistance. Figure 6, below, shows the exponential trend for each sensor on the right hand obtained from the human subject tests. Because the sensors are manufactured in batches the different batches can have different responses. This is the most likely reason why there is a difference in the sensors responses for the different fingers. This could also be due to fit of the glove and mounting of the sensor. However, we did examine Male vs Female data as a proxy for hand size, and found a similar curve fit, so hand size alone is not the likely reason.

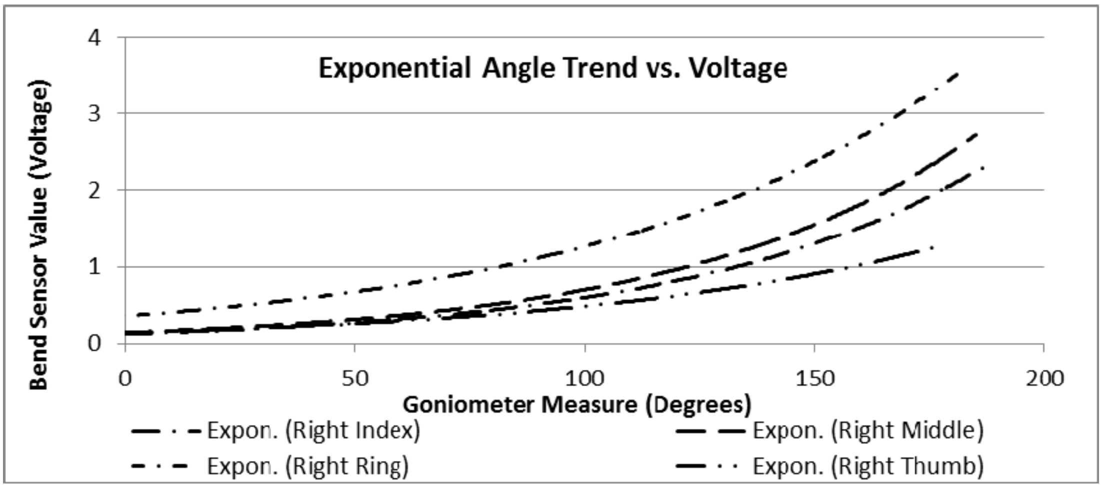

Figure 6. *Chart of exponential angle trend vs. sensor voltage*

3.2 Inertial Measurement Unit (IMU) Analysis

Data was collected over ten subjects for the IMU testing. The angles found in the charts below are based on Euler navigation angles where 180° corresponds neutral in the wrist for roll and pitch and true north in terms of yaw. The following charts display the results found from the IMU testing in Euler angles.

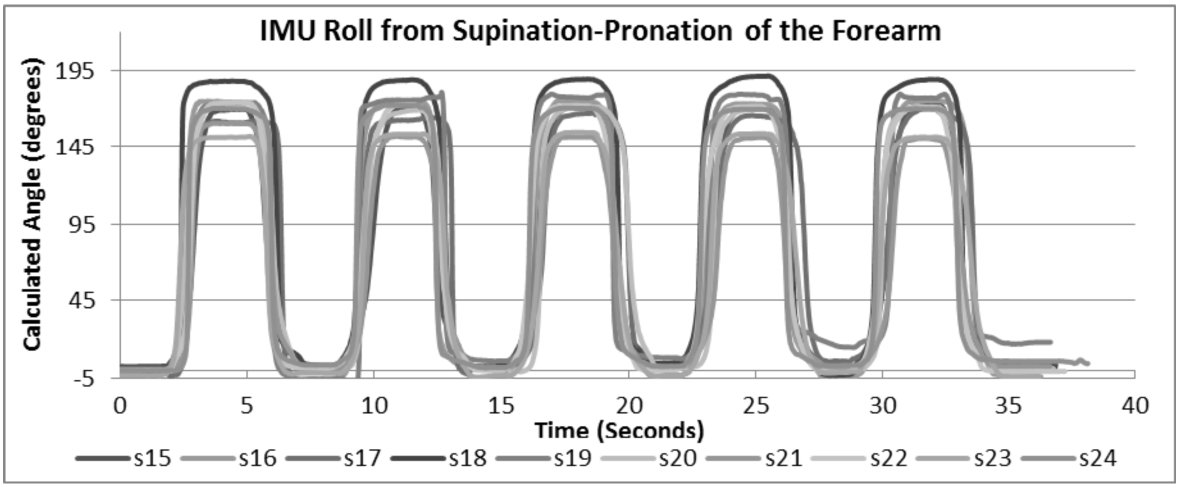

Figure 7. *Chart of IMU roll over five repetitions of forearm supination and pronation*

The chart above displays the results of the roll test across the 10 subjects. Each subject was able to maintain the cadence of the metronome that was used to time the movements and stayed within the expected range for supination and pronation (Norkin & White, 2009).

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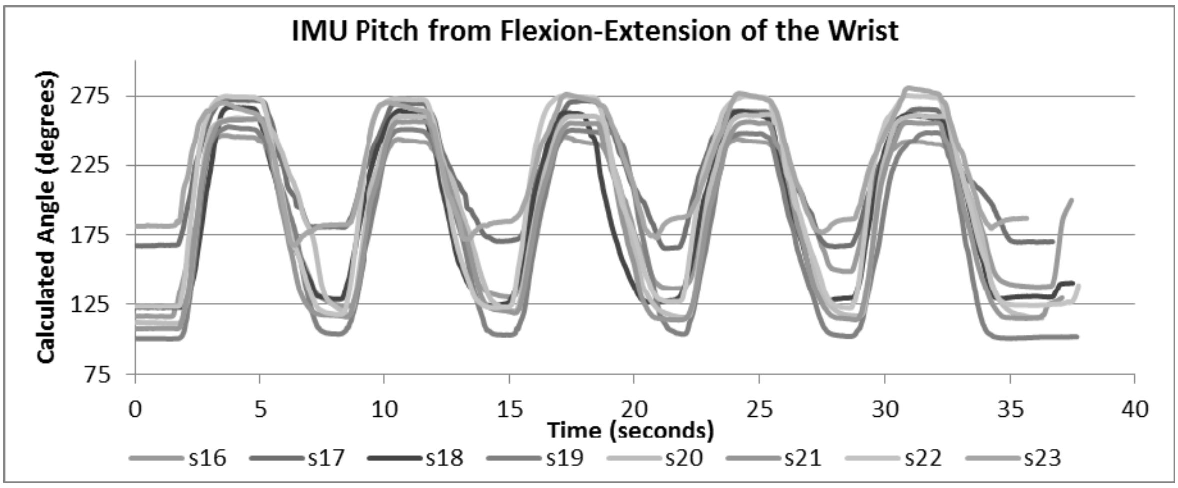

Figure 8. *Chart of IMU pitch over five repetitions of wrist flexion and extension.*

The pitch results, above, were only analyzed on 8 subjects as the data for two subjects was corrupted for this measure. As mentioned previously the angle corresponds to the Euler angle so that neutral for the wrist is 180°. Again the subjects were able to follow the cadence of the movement and the angles found were within the expected range for wrist flexion/extension (Norkin & White, 2009).

The results of the yaw testing are in the chart below. The Euler angle for the yaw test is 180° for true north. The variations seen in the initial angles of the tests are due variations of subjects' position relative to true north at the beginning of the test, not variations in wrist position itself. All subjects began in radial deviation, moved to neutral, then ulnar deviation, back to neutral, and so on. The subjects' range of movement was comparable to the guide used for the testing and the normal range expected for the movement (Norkin & White, 2009).

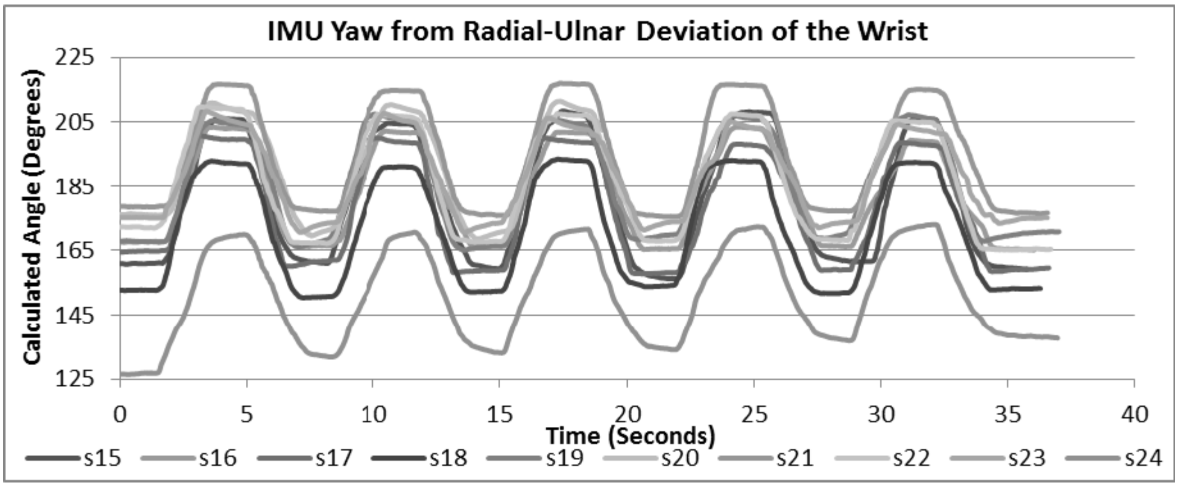

Figure 9. *Chart of IMU yaw calculation over five repetitions of radial-ulnar deviation*

3.3 Virtual Scene Development

Four scenes have been developed, 2 for direct and 2 for indirect modes. Figure 10, below, shows an example for one direct-indirect pair of scenes designed to train wrist extension with finger extension.

4. CONCLUSIONS AND FUTURE WORK

We plan to revise the electronics in the amplifier to yield a more linear response curve for the voltage-goniometer mapping, and assess further how hand size specifically affected this mapping. Finally, using these data, we plan to develop a calibration algorithm to adjust system output for variations in hand size, if it proves necessary to improve system accuracy.

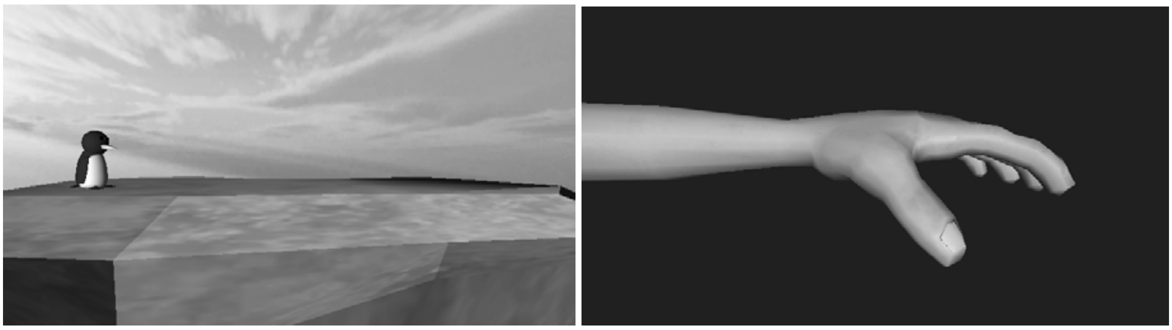

Figure 10. *Direct and indirect mechanics for a virtual scene for the ATLAS*

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What are the current limits of the Kinect™ sensor?

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ABSTRACT

The Kinect sensor offers new perspectives for the development and application of affordable, portable and easy-to-use markerless motion capture (MMC) technology. However, at the moment, accuracy of this device is still not known. In this study we compare results from Kinect (MMC) with those of a stereophotogrammetric system (marker based system [MBS]). 27 subjects performed a deep squatting motion. Parameters studied were segments lengths and joint angles. Results varied significantly depending on the joint or segment analysed. For segment length MMC shows poor results when subjects were performing movement. Differences were also found concerning joint angles, but regression equations were computed for each joint that produced the same results for MMC and MBS after correction.

1. INTRODUCTION

Human motion tracking is widely used for movement analysis. Movement analysis has numerous applications: security, biomechanical analysis, medical diagnosis, serious or fun gaming… Currently, the majority of human motion tracking is performed using Marker Based System technologies (MBS) (Cappozzo et al. 2005), especially for medical purposes (Galli et al. 2012). Despite this important use MBS presents many disadvantages: these devices are very expensive, MBS's are placed in movement analysis laboratories and are difficult to transport. One of the most important problems of MBS is the markers placement: this step is time consuming and a potential source of error (palpation error [Cappozo et al. 1995] and error due to skin displacement [Leardini et al. 2005]). So, results of these exams should be interpreted with caution (Moe-Nilssen 2011), and are only reproducible for a large range of motion (Capozzo et al. 1996).

The majority of these problems due to marker placement can be avoided a using Markerless Motion Capture system (MMC). Although this technology has been developed since twenty years (Rohr 1993, Gavrila and Davis 1995, Regh and Kanade 1995), and offers interesting perspectives in the biomedical field, MMC is still, for the moment, rarely used in biomechanics despite numerous advantages: there is no time spent placing markers, and no error due to makers placements, generally these systems are more affordable and portable than MBS. Too often the accuracy of MMC is unknown, which can lead to reluctance from potential clinical users. As previously mentioned, MBS shows reproducible measurement only for large motion, while MMC precision depends on the number of cameras used (single [Wagg and Nixon 1996] or multiple cameras [Kakadiaris and Metaxes 1995]), and the types of algorithms used (constraint propagation [O'Rourke and Badler 1980], optical flow [Bregler and Malik 1997], silhouette based technique [Bottino and Laurentini 2001], fuzzy clustering process [Marzani et al. 2001], …)

The recent availability of the Kinect™ sensor - PrimeSense technology (Tel Aviv, Israel) (Freedman et al. 2010, Shpunt 2010, Spektot et al. 2010) – a single low cost and transportable camera that can be used as MMC shows new interesting possibilities, not only for games, but also in the revalidation (i.e. for serious gaming applications [Chang et al. 2011]) and biomechanical field (i.e. a quick tool to assess joint mobility before and after therapeutic protocol).

Before any use in clinics, accuracy of such a device must be evaluated, which has, to our knowledge, not been done yet.

2. MATERIAL AND METHOD

2.1 Population

Twenty seven healthy adults (average age: 31 ± 12 years old, average height: 174 ± 7 cm, average weight: 71 ± 9 kg, BMI = 23 ± 3 kg/m², 7 women, 20 men) participated in this study. This study was approved by the Ethical Committee of the Erasme Hospital (CCB: B406201111989) and written informed consent was obtained from all subjects prior to participation in the study.

2.2 Material

The Kinect camera (PrimeSense's 3D sensor) was used as a markerless motion capture device. The skeleton model (stick figure composed of 20 points, see Figure 1) used to estimate segment length and orientation was obtained using the Microsoft Kinect SDK software (Beta 1) installed on a laptop (Intel Core(TM)2 CPU T7200@2GHz, 2Go RAM, Windows 7 Professional). The sensor was placed on a tripod 1.5 meter from the ground, and subjects were placed at a distance of 2 meters from the camera, as recommended by the manufacturer (http://support.xbox.com/kinect/getting-started/home). The Kinect camera doesn't require any calibration; whenever a subject is in the camera's field of view his/her stick figure skeleton is automatically created. The measurement frequency of the Kinect sensor is approximately 30Hz (frequency varies slightly during operation).

A stereophotogrammetric system (Vicon, 8 MXT40s cameras, Vicon Nexus software, recording frequency was set at 60Hz) was used as gold standard to compare results from the Kinect sensor. 32 markers were placed on the subject to obtain a skeleton as similar as possible to the one obtained from MMC.

Segment lengths studied in this study were: arm, forearm, hand, thigh, shank, foot and trunk. For the angles, the Kinect skeleton model is composed of only 20 points, so only "big" articulations can be studied: shoulder, elbow, wrist, hip, knee, ankle and angle between trunk and pelvis were compared.

2.3 Data Collection

Subjects were placed two meters from the camera. A first file was recorded without performing any motion (static posture) subjects were then asked to perform a deep squatting motion (initial and end of the motion position are presented in Figure 1). No particular instruction was given about upper limb movement or foot position, or about the speed of motion.

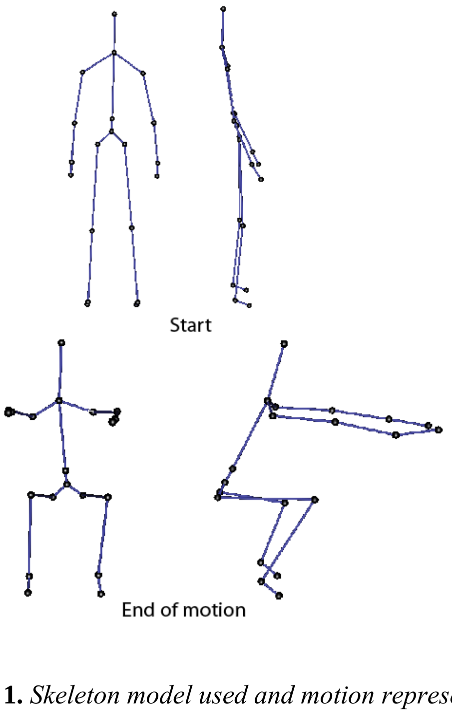

Figure 1. *Skeleton model used and motion representation.*

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2.4 Data processing and statistics

A low-pass Butterworth filter was applied to both signals (cutof=6Hz, Order=4 (forward and reverse=filtfilt)). As there is no synchronization between both devices, the start of the first movement and end of the last movement were manually detected for each joint. Due to some small differences between the two skeleton models used, the zero point of the joint was defined on the first frame of the files (neutral position). Finally, the two signals were then time normalized.

Normality of data was checked using the Kolmogorov-Smirnov test, as data was normally distributed parametric tests could be used. For segment lengths - as the Kinect skeleton model is not fixed - Paired Student t-tests were applied to compare results obtained during both static and dynamic conditions (level of significance was set at p<0.05). Differences between the two conditions were expressed in mm and in percentage of change from the static posture. For the analysis of joint angles Range of Motion (RoM) (difference between minimal and maximal values) and mean values were computed. Paired Student t-tests and Pearson coefficient correlation were computed to compare both devices. Root Mean Square (RMS) and Coefficient of Multiple Correlation (CMC) were calculated to compare curves (example of curves for different joints are presented in Figure 2).

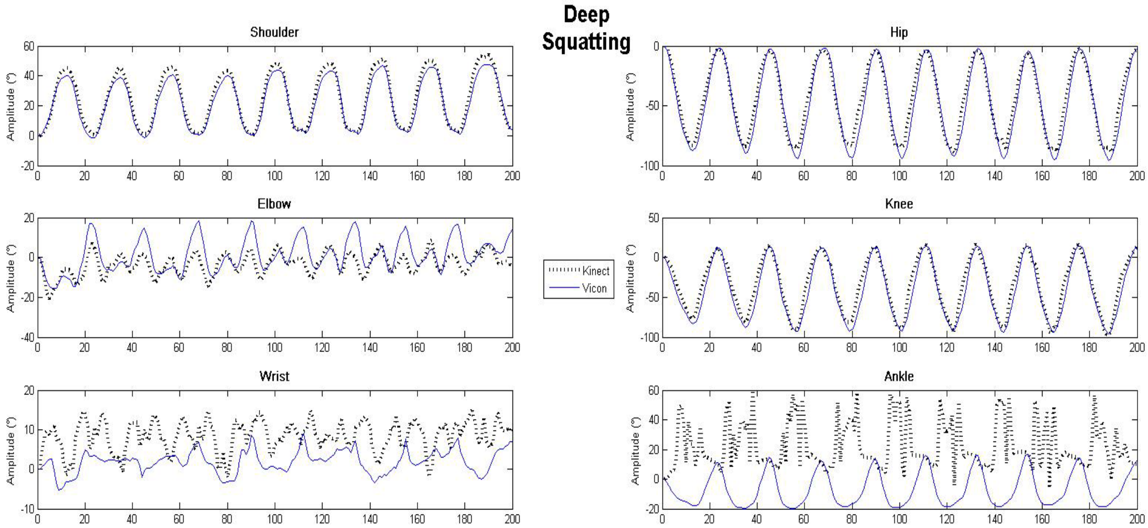

Figure 2. *Curves for different joints (from one subject)*

3. RESULTS

3.1. Segment Lengths

Results for both devices are presented in Table 1. For Vicon no difference was found between static posture and during deep squatting. For Kinect difference were found for arm (-7 (7)%, p<0.001), for hand (23 (35)%, p<0.001), for trunk (-5 (4)%, p<0.001), for thigh (-11 (3)%, p<0.001) and for foot (-4 (11)%, p=0.005). Despite these differences there are significant correlations between each segment length in static posture and during dynamic condition.

3.2. Estimation of Angles

Results are presented in Table 2. For the shoulder no difference was found for RoM (p=0.99), nor for mean (p=0.83), RMS was 7 (3)° and CMC=0.95 (0.04). For the elbow no difference was found for RoM (p=0.06), difference was found for mean (4 (5)°, p=0.001), RMS was 9 (5)° and CMC 0.59=(0.22). For the wrist differences were found for RoM (16 (17)°, p<0.001) and for mean (5 (8)°, p=0.006), RMS= 12 (5)° and CMC= 0.60 (0.25). For the hip differences were found for both RoM (-5 (6)°, p=0.001) and mean (6 (4),p<0.001), RMS was 12 (6)° and CMC= 0.91 (0.06). For the knee no difference was found for RoM (p=0.83), but differences were found for mean (8 (7)°, p<0.001), RMS= 20 (7)° and CMC= 0.91 (0.07). For the ankle differences were found for both RoM (61 (39)°, p<0.001) and mean (8 (11)°, p=0.002). For the trunk differences were found for RoM (11 (13)°, p<0.001) and for mean (-3 (7)°, p=0.03), RMS=11 (4)° and CMC=0.78 (0.14).

Table 1. *Segment length variation during deep squatting. Mean values (and standard deviation) are given in mm. * correlation is significant at percentile 0.01 α p=0.05. For length (column 2 and 3) first lines are Kinect's results, second line in italic are Vicon's ones.*

Difference = Static posture – Deep squatting.

Segment	Length		Kinect				Vicon			
	Static posture	Deep squatting	Diff. (mm)	Diff. (%)	P-value	R	Diff. (mm)	Diff.(%)	P-value	R
Arm	275 (19) *331 (18)*	256 (25) *322 (19)*	-19 (20)	-7 (7)	***<0.001***	0.63*	-8 (9)	-2 (3)	0.96	0.86*
Forearm	240 (17) *259 (17)*	242 (20) *262 (28)*	2 (11)	1 (5)	0.19	0.82*	4 (8)	1 (6)	0.24	0.75*
Hand	80 (18) *84 (8)*	95 (20) *84 (8)*	15 (23)	23 (35)	***<0.001***	0.27*	-1 (2)	-1 (2)	0.91	0.96*
Trunk	411 (20) *439 (30)*	389 (23) *438 (31)*	-22 (16)	-5 (4)	***<0.001***	0.73*	0 (11)	0 (3)	0.79	0.94*
Thigh	453 (53) *407 (23)*	402 (41) *399 (24)*	-52 (18)	-11 (3)	***<0.001***	0.96*	-9 (6)	-2 (1)	0.10	0.97*
Shank	368 (35) *420 (27)*	361 (36) *416 (26)*	-7 (28)	-2 (8)	0.08	0.67*	-6 (5)	-1 (1)	0.34	0.98*
Foot	91 (11) *152 (16)*	86 (7) *148 (15)*	-4 (11)	-4 (11)	***0.005***	0.39*	-4 (4)	-1 (2)	0.62	0.84*

4. DISCUSSIONS

Concerning the estimation of segment lengths, statistical differences were found for nearly each segment during the motion except for forearm and shank. It is interesting to note that it is the same portion of the appendicular skeleton that did not present length variation for upper and lower limb. To be sure that these differences were only explained by the motion and were not due to the lack of reproducibility of the MMC results, we compared the static posture with the ten first frames (during which the subjects did not move) of the deep squatting file. No differences were found, thus the observed differences are only due to displacement of joint center estimation during the movement.

Concerning the estimation of angles results were very different depending on the joints (excellent results for shoulder, very poor for wrist and ankle) for RoM and mean values. Yet, if we look at the RMS it seems that the elbow (9 [5]°) is better than the hip (12 [6]°), despite the fact that curves seem much better for the hip than the elbow (see Figure 2). RoM was different for each joint so RMS was expressed in percentage of mean RoM for Kinect and Vicon. Results are presented in Table 2 (in italics on the right of RMS values). Expressed in percentages, results for the hip (16 [7]%) are smaller than results for the elbow (28 [10]%), these results are consistent with CMC. Putting all these results together, joints can be put into two groups: shoulder, hip and knee with good results and elbow, wrist, ankle and trunk with poor results.

Regarding both segment length variations and estimation of angles, there is no clear pattern that emerges: shoulder's angle estimation is accurate with Kinect but arm and trunk estimation vary throughout the motion, ankle's angle estimation is poor, but shank estimation remains stable during the motion…

Finally, for each joint a regression equation was computed in order to see if it was possible to apply some corrections to MMC results to get more precise results (closer to those of MBS). Due to the relatively small size of the population a leave-one-out method was used (Ripley 1996). Kinect values before and after correction and statistics are presented in Table 3. After correction, no difference was found between the two devices. Although regression equations (Eq.1 to 7) can be used to correct results from Kinect. it is quite obvious that there are differences between equations. For shoulder abduction the coefficient of determination was 0.87 but for the elbow angle, R^2 was only 0.08 thus the measurement variable (Kinect expressed in degrees) does not carry much weight compared to the constant introduced in the independent term (see Eq. 2). A similar limitation was observed for wrist (R^2=0.11) ankle (R^2=0.28) and trunk (R^2=0.20). Bland and Altman plots were finally computed and are presented in Figure 3 (Bland and Altman 1986).

$$\textit{Shoulder}\ (°) = 0.68 * \textit{Kinect}\ (°) + 18° \qquad R^2=0.87 \tag{1}$$

$$\textit{Elbow}\ (°) = 0.40 * \textit{Kinect}\ (°) + 16° \qquad R^2=0.08 \tag{2}$$

$$\textit{Wrist}\ (°) = 0.22 * \textit{Kinect}\ (°) + 16 \qquad R^2=0.11 \tag{3}$$

$$\textit{Hip}\ (°) = 0.84 * \textit{Kinect}\ (°) + 17° \qquad R^2=0.88 \tag{4}$$

$$\textit{Knee}\ (°) = 0.91 * \textit{Kinect}\ (°) + 7° \qquad R^2=0.77 \tag{5}$$

$$\textit{Ankle}\ (°) = 0.06 * \textit{Kinect}\ (°) + 34° \qquad R^2=0.28 \tag{6}$$

$$\textit{Trunk}\ (°) = 0.67 * \textit{Kinect}\ (°) + 1° \qquad R^2=0.20 \tag{7}$$

Table 2. *Range of Motion and statistics for studied joints. Values (and standard deviation) are expressed in degrees.*

Difference = Kinect – Vicon

$^{\alpha}p<0.05$ $^{\alpha\alpha}p<.01$ $^{\alpha\alpha\alpha}p<0.001$ ** correlation is significant at percentile 0.01 α p=0.05.*

Articulation	Measure	Kinect	Vicon	Difference	R
Shoulder	RoM (°)	58 (18)	58 (16)	0 (6)	0.94*
	Mean (°)	25(10)	25 (11)	0 (3)	0.96*
	RMS (°)	7 (3) – *11 (5)*			
	CMC	0.95 (0.04)			
Elbow	RoM (°)	40 (26)	29 (15)	11 (27)	0.28
	Mean (°)	-2 (11)	-6 (13)	**4 (5)** $^{\alpha\alpha}$	0.91*
	RMS (°)	9 (5) – *28 (10)*			
	CMC	0.59 (0.22)			
Wrist	RoM (°)	35 (19)	18 (9)	**16 (17)** $^{\alpha\alpha\alpha}$	0.42*
	Mean (°)	3 (5)	-2 (5)	**5 (8)** $^{\alpha\alpha}$	-0.22
	RMS (°)	12 (5) – *47 (20)*			
	CMC	0.60 (0.25)			
Hip	RoM (°)	73 (17)	78 (16)	**-5 (6)** $^{\alpha\alpha}$	0.93*
	Mean (°)	-25 (8)	-31 (8)	**6 (4)** $^{\alpha\alpha\alpha}$	0.89*
	RMS (°)	12 (6) - *16 (7)*			
	CMC	0.91 (0.06)			
Knee	RoM (°)	107 (27)	107 (22)	0 (14)	0.87*
	Mean (°)	-31 (9)	-40 (9)	**8 (7)** $^{\alpha\alpha\alpha}$	0.75*
	RMS (°)	20 (7) – *19 (6)*			
	CMC	0.91 (0.07)			
Ankle	RoM (°)	90 (36)	29 (8)	**61 (39)** $^{\alpha\alpha\alpha}$	-0.27
	Mean (°)	1 (11)	-7 (5)	**8 (11)** $^{\alpha\alpha}$	0.20
	RMS (°)	22 (6) – *40 (13)*			
	CMC	0.47 (0.22)			
Trunk	RoM (°)	50 (10)	39 (16)	**11 (13)** $^{\alpha\alpha\alpha}$	0.58*
	Mean (°)	-15 (7)	-11 (8)	**-3 (7)** $^{\alpha}$	0.63*
	RMS (°)	11 (4) – *25 (10)*			
	CMC	0.78 (0.14)			

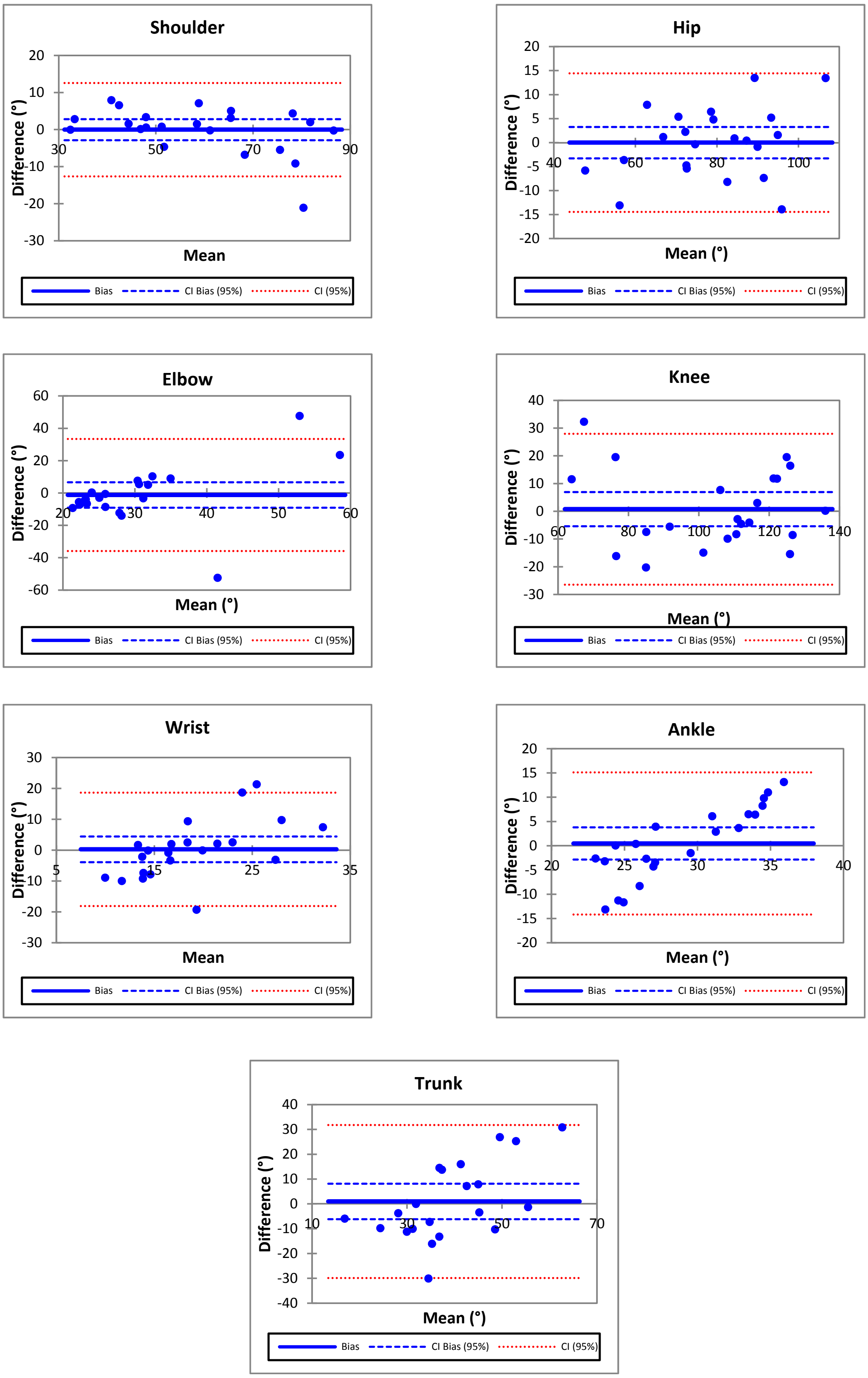

Figure 3. *Bland and Altman plots for the seven studied joints (after correction of Kinect's results).*

Table 3. *Kinect Results before and after correction.*
Difference = Kinect Processed - Vicon
** correlation is significant at percentile 0.01 α p=0.05.*

Articulation	Kinect	*Kinect Processed*	Vicon	Difference	P	R
Shoulder	58 (18)	***58 (15)***	58 (16)	0 (6)	0.94	0.93*
Elbow	40 (26)	***30 (10)***	29 (15)	1 (17)	0.75	0.28
Wrist	35 (19)	***19 (5)***	18 (9)	0 (9)	0.92	0.33
Hip	73 (17)	***78 (14)***	78 (16)	0 (7)	0.98	0.94*
Knee	107 (27)	***106 (23)***	107 (22)	-1 (14)	0.78	0.88*
Ankle	90 (36)	***29 (2)***	29 (8)	0 (8)	0.99	0.53*
Trunk	50 (10)	***39 (8)***	39 (16)	0 (16)	0.91	0.45*

5. CONCLUSION

This study showed some limits of the Kinect. The first one being that Kinect does not necessarily obtain precise segment lengths during motion. When used as a game it is maybe not a big deal, but for potential future biomechanical application this is a big problem (i.e. 3D modeling). A priori, for some joints, there are very important differences for Range of Motion, but actually for each joint a regression could be found that perfectly fits the results of Kinect to those of Vicon. In order to get precise results with the Kinect a kind of calibration (a simultaneous recording of each particular motion with both MMC and MBS) is required to estimate regression equations that would be used to correct these results. This study provides interesting perspectives in the field of medical serious game. Kinect could be used for at home for rehabilitation exercises. Patients receive a live feedback and corrections can be done directly in order to avoid incorrectly executed motion that could potentially lead to counterproductive results. A couple of games for revalidation of children with cerebral palsy is under development taking into account the observed limitation of the Kinect (Omelina et al. 2012).

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Virtual reality learning software for individuals with intellectual disabilities: comparison between touchscreen and mouse interactions

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ABSTRACT

The aim of this article is to analyze the impact of two user interfaces - a tactile interface and a computer mouse - on a virtual environment allowing self-learning tasks as dishwashing by workers with mental deficiencies. We carried out an experiment within the context of a design project named "Apticap". The methods used were an experiment, an identification questionnaire and a post-experimentation interview, with six disabled workers. The results of this study demonstrate the interest of a virtual reality tool associated with a tactile interaction for learning of real tasks by workers with mental deficiencies.

1. INTRODUCTION

For populations with specific needs, it is currently accepted that patients suffering from mental pathologies can present important cognitive disorders which tend to reduce the efficiency of the general learning methods (Barch, 2009; Oppenheim-Gluckman et al, 2003). Nowadays most of practices for learning are built on a sequencing of the task to carry out in elementary sub-tasks (Lancioni and O' Reilly, 2002): these actions are presented on pictograms (paper or computer) or in videos (for example, AbleLink products). Beyond these traditional tools, the use of virtual environments begins to spread. Their efficiency has been demonstrated on the criteria of an easier acquisition of skills in daily life and on the transfer to the real life (Cromby et al, 1996). Moreover, virtual environments are appreciated by individuals with mental disabilities and by those suffering from cognition disorders, which is likely to increase their motivation and becomes a factor of success (Davies et al, 2003). On the other hand, the current systems focus on the discovery of new environments (i.e. a railway station or a supermarket), but are seldom used to learn simple tasks (i.e. to make the coffee or to lay the table) (Cao et al, 2010). Computer-aided learning does not aim to replace teachers, but to assist them for the learning of "simple" tasks and give them more time for more complex ones, such as coaching. The advantages of such a tool for the learning of people presenting cognitive deficiencies are proved: it avoids the frustration of learners by allowing them to work at their own pace, without the critical look of the others (Standen and Brown, 2006). Moreover, it intensifies the motivation of learners and allows to test several jobs before choosing one, which it would be difficult to perform in real-world in terms of time (Standen et al, 2000).

That is the reason why it seems relevant to develop a tool using the technologies of virtual reality to assist the learning of workers with disabilities. The chosen interaction technique should be optimal in order to make the designed tool usable. A large body of research demonstrates the value of touchscreens for individuals without mental disabilities (Sears and Shneiderman, 1991; MacKenzie and Soukoreff, 2002). So, we assume that a touchscreen seems more adapted for individuals with mental disabilities, considering the progress of this technology. The objective of this study is to refute or validate this assumption.

The scientific objective of this paper is to compare two interaction techniques, a mouse and a touchscreen, for performing a washing dishes task in a virtual environment by individuals with intellectual deficiencies. Related to this objective, we try to assess that the "tactile" interface allows better performances and is better accepted than the "mouse" by individuals with mental disabilities when using a virtual environment dedicated to learning.

The article is organized in this way: in the second section, we describe the context of the experiments in the "Apticap" project. In the third section, we present the assumptions that underpin our research work, the

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experimental protocol implemented in order to collect data as well as the method to analyze them. In the fourth section, we present the results obtained. To conclude, we put in perspective our results with our initial hypotheses and we compare them with the literature and we summarize the main elements of the study and highlight their limits before opening on research perspectives.

2. THE APTICAP PROJECT

This design project aims to develop virtual reality tools for vocational guidance and learning of disabled workers in ESAT. We developed virtual reality software which enables individuals with mental disabilities to learn the dishwashing activity in a semi-autonomous way. It would thus replace the common techniques used in ESAT (i.e. learning through oral repetition or videos and pictograms) which have a limited efficiency according to the monitors and the technical educators.

Two kinds of users are concerned with this tool, as they will interact with the software to complete their work (Darses, 2004): disabled workers (i.e., people having limited intellectual abilities) and professionals (i.e., monitors and educators). This explains why the software presents two menus:

- *Worker menu*. It enables the users to identify themselves via their own pictures and to access the various activities proposed.
- *Educator menu*. It is accessible via a password, enables the educators to access all workers profiles and to follow-up their results for the several activities.

The implemented activity of dishwashing (the washing-up) is broken up into three tasks corresponding to procedures really applied in ESAT.

The first task is to receive the dirty dishes (plates, glasses and cutlery). Specifically, the user begins by choosing the correct basket for the task. Then the dishes are brought by an avatar: the user has to pile up the plates, store glasses in the basket, place the cutlery in a small basket and then place this small basket in the large one.

Figure 1. *Reception of dirty dishes.*

The second task corresponds to the rinsing out of the dirty dishes, especially plates. Concretely, dirty plates are placed on the right of the sink and the user has to open the tap and rinse the plates.

Figure 2. *Rinsing out of the dirty dishes.*

The third task corresponds to the putting away of the rinsed dishes in the baskets.

Figure 3. *Putting away of the rinsed dishes into baskets.*

Beyond these tasks, the tool enables the user to visit the kitchens in a first person perspective and to watch several educational videos related with the tasks of dishwashing (i.e., to rinse the plates). First person view means that the visual sight angle simulates the vision field of the user.

3. METHODS

3.1 Experimental assumptions

The scientific objective is to compare two different user interfaces, a mouse and a touchscreen, for performing a washing dishes task in a virtual environment by individuals with intellectual deficiencies. Related to this objective, we make the following hypothesis: "*Tactile" interface allows better performances and is better accepted than the "mouse" by individuals with mental disabilities when using a virtual environment dedicated to learning.*

This hypothesis connects an independent variable (i.e. interaction mode) and two dependant variables (i.e. performance and acceptability). The independent variable "interaction mode" has two forms: touchscreen and mouse. The dependant variable "performance" is measured by a temporal indicator (in seconds). The dependant variable "acceptability" is measured by two indicators: feelings about ease of use, feelings about pleasure.

Therefore we make the following operational hypotheses:

- *h1*. Individuals with mental disabilities have better performances with the touchscreen than with the mouse.
- *h2.* The touchscreen is better accepted. It is perceived as easier to use and more convenient by individuals with mental disabilities than the mouse.

3.2 Experimental protocol

3.2.1 Participants. This study implied six participants (2 women and 4 men) who suffer from a congenital mental deficiency. The participants were on average 26.3 years old (S.D. = 4.4 years; Min = 21; Max = 32) and have 5.3 years of work experience (S.D. = 4.1 years; Min = 1; Max = 13). We mean by "work experience", the number of years of practice of the dishwashing activity at the ESAT.

3.2.2 Material. We used the following material:

- *a DELL XPS 430 PC* (Intel Core 2 Quad 2.83 GHz, 4 Go of RAM, ATI Radeon 3870 X2) with the APTICAP tool as support of the experiment;
- *a mouse with optical technology and a 22'' touch screen* (Iiyama ProLite T2250MTS-B1) which correspond to the two interaction modes;
- *a voice recorder* (Olympus VN-5500PC) to record the answers of the interviewees;
- *an identification guide* containing all questions to characterize the participants (i.e., how old are you?, how long have you worked with the ESAT?, and so on) and questions linked with the washing tasks (i.e., have you ever performed dishwashing activities?, which task are you doing when you are washing the dishes?, and so on);
- *an observation grid* centered on temporal performances and participants' comments during the experiment;

- *post-experimentation questions* to collect all participants' judgments and preferences for each interaction mode (i.e., which interaction mode did you prefer?, which one did you find most pleasant? and so on) and to help them to imagine their future use of the tool (i.e., which one would you choose to work during a long time?, would you be ready to use this application alone?, and so on);
- *a basket and five plates* in order to demonstrate the real task.

3.2.3 Procedure. We carried out an identification interview of each participant before the experiment. The experiment was composed of several steps. After giving the instructions to the participant (to carry out the task with the two user interfaces) we demonstrated how to put away five plates in a basket firstly in reality and secondly in the virtual environment. Then, we let the participant familiarize himself with the software and the task to perform, during one minute. Finally, the participant performed the task into the virtual environment. The test was repeated twice for each interaction mode. The presentation order was counterbalanced (i.e. we alternate the presentation order after each participant). Then, we interviewed the participant on his perception of each interaction mode and more generally on the APTICAP tool.

3.2.4 Experimental conditions. Interviews and experiments were performed in two rooms of the ESAT; these rooms were isolated from other workers and parasitical factors (eg., noise). The participants performed the experiments during their work hours. So, we took a particular care to take away the 2 workers simultaneously present.

Three people were simultaneously present in the first room for experiment:

- *Experimenter*. He presented the "Apticap" tool and explained the instructions to participants.
- *Observer.* He reported times and comments.
- *Disabled worker*. He was interviewed.

Three people were simultaneously present in the second room for interviews:

- *Interviewer*. He carried out the interviews.
- *Educator*. He helped the interviewer to rephrase questions according to the answers and attitudes of the interviewees.
- *Disabled worker*. He performed the experiment.

3.2.5 Collected data. Two data types were collected: times and verbalizations. We recorded execution times for the two attempts with each interaction mode and for the six participants. Comments were the 54 answers to binary type questions (i.e. mouse or touchscreen): each participant gave 9 answers on average; some participants were not able to answer all questions. It also could be justifications and suggestions although these last ones were very rare because of the interviewed population.

3.3 Analysis method

Concerning the performances analysis, we used the traditional descriptive statistics for the execution time (i.e. average, deviation, minimum, maximum) to compare the two interfaces. When it was possible, we also carried out a simple statistical analysis based on the Student t-test for paired samples. More qualitatively, we then verified if the tendency were confirmed for each of the six participants and if there were or not improvement (i.e. time saving) between the two attempts for each interaction mode.

Concerning the analysis of the post-experimentation interviews which was focused on preferences and subjective judgements concerning the two interaction modes, we counted the frequencies for each user interface evoked for each question. The qualitative analysis aimed to find the favourite interface for each participant, to know why, thanks to the answers to the other questions (ease of use, convenience, fidelity compared to the real task) and to analyze how participants would use it in the future (alone or guided by a educator, and so on).

Finally, we confronted the performances and the preferences of each answers of the participants for each of them to establish a qualitative relation between these two criteria.

4. RESULTS

Table 1 presents raw data corresponding to the time required to complete the task, for each interaction mode (touchscreen vs. mouse) and each attempt, for the six participants. These data will be used in the following sections presenting the main results.

Table 1. *Execution time (in seconds), for each participant and each attempt.*

	Mouse		Touchscreen	
Participant	1st attempt	2nd attempt	1st attempt	2nd attempt
1	21	23	15	23
2	29	42	43	26
3	40	49	49	41
4	24	15	21	16
5	23	22	23	21
6	29	19	23	15

4.1 Participants were faster with the touchscreen than with the mouse

When considering the twelve attempts (two attempts per participant) for each interaction mode (see Figure 4), we observe that participants performed the task slightly more quickly with the touchscreen (mean = 26.3; S.D. = 11.0) than with the mouse (mean = 28, S.D. = 9.8), although extreme data are identical in both cases (min = 15 seconds, max = 49 sec). Averages values (considering the two attempts) for each participant and each interaction mode are presented in Table 2.

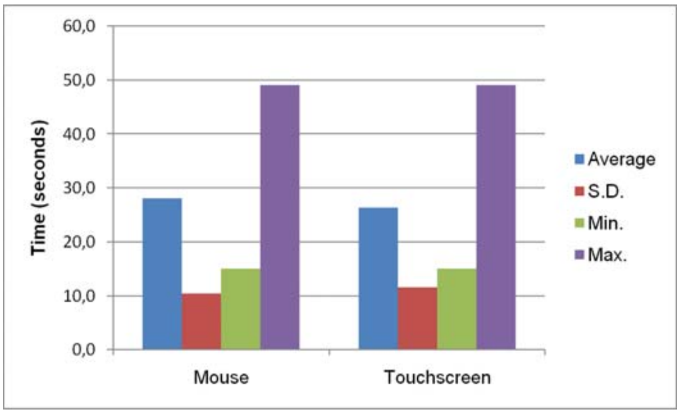

Figure 4. *Indicators (average time, minimum, maximum and S.D.) for the mouse and the touchscreen.*

Table 2. *Average times of each participant for each interaction mode.*

Participant	Mouse	Touchscreen
1	22	19
2	35,5	34,5
3	44,5	45
4	19,5	18,5
5	22,5	22
6	24	19

Qualitatively, we observe that two participants out of six (participants 1 and 6) were significantly faster with the touchscreen, considering a difference of execution time greater than 15%. For three of the remaining participants, execution times were only slightly lower with the touchscreen (participants 2, 4 and 5). Finally, one participant (participant 3) performed better with the mouse, although the execution time was very close to the one obtained with the mouse (44.5 vs. 45 seconds). A statistical analysis based on a Student t-test for paired data confirms these results: we observe a trend ($t = 2.050$, $p < 0096$) which should be confirmed or invalidated with more participants.

As detailed in the next subsection and illustrated in Table 1, the execution time for each participants vary from the first attempt to the second one. Contrary to our expectations, an improvement is not systematically observed. Consequently, we have completed our performance analysis by considering the best attempt (in terms of execution time) with each interaction mode, for each participant (Table 3).

Table 3. *Best execution time (in seconds) with each interaction mode for each participant.*

Participant	Mouse	Touchscreen
1	21	15
2	29	26
3	40	41
4	15	16
5	22	21
6	19	15

The average execution time is equal to 24.3 seconds for the mouse (S.D. = 8.9) against 22.3 seconds for the touchscreen (S.D. = 10.1), which represents a slight gain for the mouse. A Student paired t-test does not give any significant difference between the two interaction modes ($t = 1.732$, $p < 0.144$).

4.2 A more important speed gain with the touchscreen than with the mouse

To study the participants' progresses between the two attempts with the two interaction modes, we compute differences between execution times of each attempt. Results are summarized in Table 4.

Table 4. *Differences between execution times of each attempt (2nd attempt – 1st attempt) for each participant and each interaction mode.*

Participant	Mouse	Touchscreen
1	2	8
2	13	-17
3	9	-8
4	-9	-5
5	-1	-2
6	-10	-8

If we consider the two attempts independently for each interaction mode (Figure 5), we observe a better progress with the touchscreen than with the mouse, regarding execution times. Indeed, the touchscreen allows to save five seconds in average (first attempt: average = 29 s, S.D. = 14 s / second attempt: average = 24 s, S.D. = 9 s) for the first attempt to the second one, when average execution times for the two attempts are similar with the mouse (first attempt: average = 28 s, S.D. = 7 s / second attempt: average = 28 s, S.D. = 14 s).

As presented in Table 4, the trend indicating that the touchscreen allows to reduce the execution time between two attempts is confirmed for five people (participants 2 to 6). Like for the mouse, only three participants are faster during their second attempt (participants 1, 2 and 3). When participants saved time between the two attempts, the difference with the mouse is higher than with the mouse for two participants (participants 4 and 6) and lower for the participant 5.

4.3 The touchscreen is perceived as easier and more pleasant than the mouse

The analysis post-experimentation interviews regarding the perceptions of the two interaction modes shows that four participants (participants 1, 2, 3 and 4) prefer the touchscreen and two like "both of them" (participants 5 and 6).

The participants who preferred the touchscreen gave the following explanations:

- It's easier than the mouse (participant 1);
- It is more pleasant with the touchscreen but easier with the mouse (participants 2 and 3);
- It is easier and more pleasant than the mouse (participant 4).

Concerning the participants who had no preference for one interaction mode or the other, one participant said that the handling was easier and more enjoyable with the touchscreen than with the mouse (participant 6);

conversely, another participant said it was not used to "touch the screen" but that the two interaction modes were easy (participant 5).

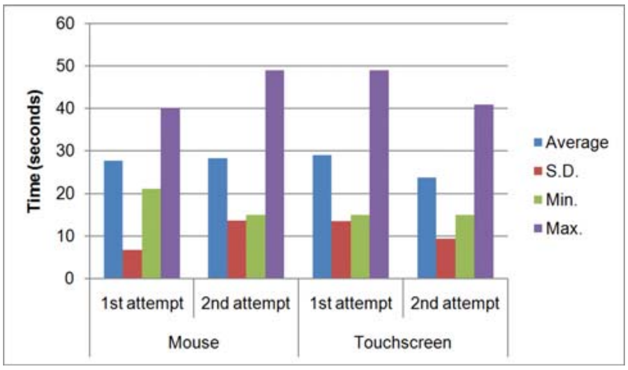

Figure 5. *Progress between two attempts for each interaction mode.*

4.4 An anticipation of the future use of "Apticap": training himself using tactile interaction

Five out of six participants were able to answer to post-experimentations questions concerning the use of "Apticap".

Four out these five participants said they would choose the touchscreen for a long-term use of the "Apticap" (participants 2, 4, 5 and 6). Questioned about the using conditions (alone or with a monitor), three answered that they would prefer to use the application with the monitor before using it alone (participants 3, 4 and 5); two said they could use the tool alone from the outset (participants 2 and 6). Ultimately, five out of six participants think they can use the software alone.

When asked about their preference for learning tasks in the real kitchen or with "Apticap", two participants said it was better in real conditions (participants 3 and 5); two participants preferred to learn with the virtual reality software (participants 2 and 4). A person (participant 6) was not able to answer to this question.

4.5 Lack of coherence between performances and subjective judgments

One participant (participant 6), who had no preferences for an interaction mode but who judged the touchscreen easier and more enjoyable than the mouse, performed better with the touchscreen (19 seconds vs. 24).

One participant (participant 1) obtained better performances with the touchscreen (19 seconds vs. 22) and preferred this interaction mode.

Finally, among the four participants who had similar performances between the two interaction modes, three indicated a preference for the touchscreen (participants 2, 3 and 4) and one participant (participant 5) expressed no preference for one or the other interaction mode.

These results highlight an absence of link between the performance obtained with both modes of interaction and the subjective preferences expressed towards them.

5. CONCLUSION

Our results confirm but qualify the h1 hypothesis which stated that "individuals with mental disabilities have better performances (i.e. are faster) with the touchscreen than with the mouse"; these results are in agreement with other research works concluding that the mouse is less efficient than other interaction methods without any "moderator". We show indeed that h1 hypothesis is true for two participants but is neither confirmed nor invalidated for four participants who got similar executions between the interaction modes. Nevertheless, the statistical analysis indicates a trend in the same lines as h1. Among cases where the hypothesis is confirmed, we observed inter-individual differences of average execution times between the two interaction modes (from 0.5 seconds to 5 seconds). We also noticed intra-individual variability between two attempts for a same interaction mode: for example, a participant performed the task with the touchscreen in 43 seconds in his first attempt, then in 26 seconds in the second one. Beyond the temporal performances, our results show an important inter-individual variability in terms of time saving between two successive attempts: for example,

with the touchscreen, we observed a gain of 2 seconds for a participant and 17 seconds for another. Furthermore, our results show that the gain was higher with the touchscreen. However, it is surprising that the second attempt allowed improved performances for 5 of the 6 participants with the touchscreen, when performances are weaker with the mouse for three participants. It remains difficult to draw a conclusion on these results by considering only 2 attempts, especially as the participants had difficulties to verbalize their actions and explain their behaviour. Nevertheless, it seems that the touchscreen allows better maintenance of the participant's performances. Thus, we can answer to h1: "on the whole, persons with mental disabilities have better performances, that is to say they are faster and save more time between two attempts than with the touchscreen than with the mouse".

Our results partly confirm the h2 hypothesis which stated that "the touchscreen is more accepted, i.e. that it is perceived as easier to use and more convenient than the mouse for individuals with mental disabilities". The results of the literature about the superiority of the touchscreen compared to the mouse shows that touchscreens require little or no learning and they are faster and more accurate than mice (Douglas and Mithal, 1997). In others words, touchscreen seems more acceptable than mouse, if we consider that usability (i.e. artefact is easy to learn and use) has an effect on the system acceptability (Davis, 1989; Brangier, 2009). Thus, four participants preferred the touchscreen and two participants did not express any preference for either interaction modes. However, among the four participants who preferred the touchscreen, the reasons given diverge: one of them found it easier than the mouse, two others consider the touchscreen more enjoyable, and finally a last participant gave both these two reasons. As for h1, we are able to answer to h2: "on the whole, touchscreen is more accepted, that is to say it is perceived easier or more enjoyable to use than the mouse by individuals with mental disabilities".

Finally, there is a lack of coherence between the performances measures of the participants and their qualitative judgments. Out of the two participants who were faster with the touchscreen, one preferred this mode of interaction when the latter expressed no preference. Out of the four other participants who obtained similar performances between the two interaction modes, three preferred the touchscreen and one expressed no preference.

These elements validate the general hypothesis, with a slight difference; "touchscreen allows better performances and is better accepted than the mouse by individuals with mental disabilities when using a virtual environment dedicated to learning". Indeed, if we got sometimes very close performances or unmarked preferences for any of the two interaction modes, the mouse is never superior to the touchscreen, either considering performances or acceptability. These results lead us to affirm the interest of a tactile interaction mode for learning tasks in virtual environments by individuals with intellectual deficiencies. They provide further confirmation of the potential of tactile interaction for specific populations. However, it remains to put to these results to the test other kinds of learning tasks.

However, the limitation of the study presented in this article concerns the number of participants with mental disabilities involved in the experiment. The main reason is the number of positives responses to our requests, due to the low availability of workers with mental disabilities. Therefore, the results of this study are tendencies that we have to confirm and to examine further. The low number of participants is a quite recurrent problem in experiments which involved person with disabilities (Klinger et al, 2006; Cardoso et al, 2006; Lee et al, 2003). However, we must emphasize that the results of this study are in line with the literature, which is encouraging. In practical terms, we should include more participants with intellectual disabilities in the experiments. It would also be necessary to widen the profile of the participants by adding individuals with physical disabilities and people with behavioural problems, with the same experimental conditions as workers with intellectual disabilities.

Moreover, a second perspective would be to conduct experiments with the same experimental design, but applied to other tasks of the dishwashing (e.g., receipting the dirty dishes, ...) or to other activities (e.g., room service, laundry).

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Development of a glove-type input device with the minimum number of sensors for Japanese finger spelling

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ABSTRACT

A glove-type input device, which can measure hand postures of human beings directly, is one of essential device to develop Virtual Reality environment. The authors have been developing a data-glove which would be able to capture hand postures according to user's demand with the minimum number of sensors. Our previous research estimated the data-glove with six sensors could measure all hand postures for Japanese Finger spellings. Thus, this paper proposes a prototype with six sensors and evaluate whether the prototype glove sensor can distinguish all hand postures of Japanese Finger spellings. This evaluation indicated that data-glove with fewer sensors than conventional number of sensors could distinguish hand postures exactly.

1. INTRODUCTION

The hearing impaired have the communication barrier, which is still a serious problem, in their social lives. Because there are few situations it could be understood, while the most familiar method of communication for the hearing impaired is sign language.

Though a lot of information recently are provided visually by rapid progress of information technologies, for example, images, e-mails, subtitles for pictures and so on, the hearing impaired seem to feel some difficulties to get information via the written phonetic Japanese, As their mother tongue, Japanese Sign Language (JSL), which has a quite different grammar system.

First of all, these systems need to have input devices to capture each word of sign language, and there are two major methods to capture hand postures. One is the vision-based method, and the other is the glove-based method (T Stamer 1998). The vision-based method frees its users from a hassle wearing devices, but it is still challenging because the vision-based method has problems as capturing not only hand postures but also whole body motions, and besides, in the case of postures of small hands being affected by lighting conditions.

On the other hand, the glove-based method can measure hand postures directly. However, the price of the gloves available for sign capturing is still expensive, then it is necessary to develop an inexpensive glove-type input device (data-glove) suitable to measure sign language.

So the authors proposed the method to define the minimum number of sensors to capture a set of the given hand postures. The previous research estimated that a data-glove equipped with six low-resolution sensors could measure whole Japanese Sign Language (JSL) finger spelling (Tabata et al 2010). The low-resolution sensor itself may be produced at low cost, then the glove consisting of the limited number of sensors may also reduce the whole expense. Thus, if the glove designed under this method is confirmed feasible by experiments, it could open up the huge possibility for glove-based systems.

The purpose of this paper is to make a prototype of data-glove with six sensors and to evaluate whether the prototype can distinguish each hand posture in JSL finger spelling given by users.

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2. RELATED WORKS

2.1 Data-glove

Hands are the most useful tools for us to deal with a lot of things in our everyday environment. Therefore, many researchers have been developing technologies for manipulating our surroundings by using human hands (Dipietro et al 2008). Above all, glove-type input device is the most popular as data acquisition system for hand movements. And the glove-type input device, which is called data-glove, is one of essential devices to develop Virtual Reality environment.

After Zimmerman had developed Data Glove (Zimmerman, 1982), a number of data-gloves has been proposed and developed over and over. Most of the data-gloves use various sensors such as optical fibers, piezo registers, carbon ink, magnetic, etc, in order to measure finger joint angles. In addition, some data-gloves, for example Pinch Glove, are equipped with contact sensors to acquire the data of contact states of fingertips. The authors also have developed a data-glove called "StrinGlove" ,which equips 24 inductcoders and nine contact sensors, to realize the consumer price of glove sensor (Kuroda 2004).

These data-gloves have been used either as a pure motion capturing device or as a command input interface. In the case of command input, the data-glove should capture just "digital" hand postures. Gesture recognition systems and sign translators are other typical and conventional examples. In these applications, data-glove are adapted to obtain some hand postures or hand motions which mean a gesture (Y.Lee et al 2007). Therefore, data-gloves have been used as a input device like keyboards and mice in several kinds of research fields (K.Tsukada 2004).

2.2 Sign Notation

Sign language is the most important communication method for the hearing impaired and has the most sophisticated coding system of human motions. Therefore, when we think about hand postures, we may refer sign notation codes as a gold standard of hand postures.

Stokoe et al (1965) studied Sign language with a linguistic view for the first time in the world, and his group claimed that sign words consisted of three elements; "Dez" (hand posture), "Tab" (location), and "Sig" (movement) and have original characters on each element. In this way, every hand posture has its own original character, but it is difficult to form exact postures of each finger.

The Stokoe's notation characters were used in many researches of sign linguistics, and recently new notation characters have been developed by referring the Stokoe's notation (Kanda 2010).HamNoSys developed by German researchers was a system of sign notation characters for computers and denoted hand postures as a set of finger postures (Hanke 2004). Kurokawa (1992) also developed the method to express hand postures by using a set of finger postures from researches of non-verbal human computer interaction.

The features of these systems are to express a hand posture by using combination of contacts of fingers and bending angles of each joint, and to classify hand postures by subjective point of view. Therefore, these systems don't make the slightly bending position have its own code, as these systems must be influenced by human perception on hand postures. Then, an analysis reports that the bending angle of each joint is classified into three levels (full bend, weak bend and stretch).

3. EVALUATION

3.1 Prototype

In the proposed algorithm shown in Figure.1, a designer subjectively denotes a set of target hand postures as a set of sensors (code-sensor relation table). Then, the set cover of the table with minimum number of sets provides the minimum number of sensors. Figure.2 shows the target hand postures (28 hand postures of JSL finger spelling). Table.1 shows the obtained set cover, and figure.3 shows the estimated data-glove for JSL finger spelling (left). The sensor consists of five two-bits bend sensors and one one-bit contact sensor.

The authors have utilized the existing StrinGlove™ as the prototype, and evaluated the glove decorated with the minimum number of sensors. And three subjects expressed the 28 hand postures this time, and the given postures are measured and investigated by the prototype shown in Figure.3. The threshold values, which were used to output two-bits and one-bit, were manually-set at approximately regular intervals. Three subjects are two females and one male.

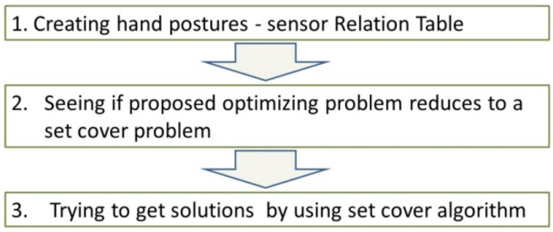

Figure 1. *Overview of our proposed method.*

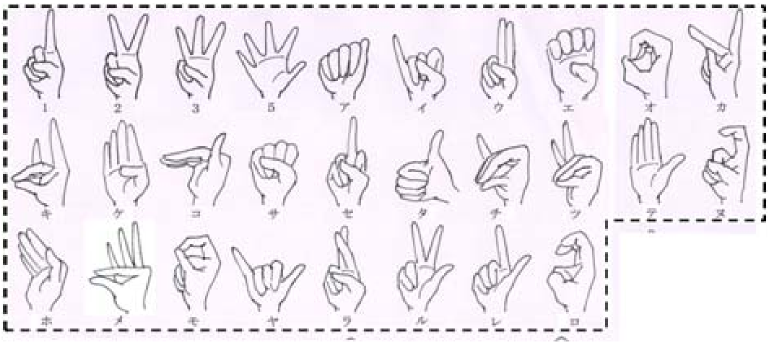

Figure 2. *Target hand posture (28 hand posture of JSL Finger spelling).*

Table1. *The obtained set cover.*

Posture ＼ Sensor	no.1	no.2	no.3	no.4	no.5	no.6
1	1	1	0	1	2	1
2	1	1	0	1	2	0
3	1	1	0	1	1	0
5	0	1	0	1	0	0
ア (A)	0	0	2	0	2	1
イ (I)	1	1	2	0	0	1
ウ (U)	1	1	0	0	2	0
エ (E)	1	0	2	0	2	1
オ (O)	1	1	1	0	1	1
カ (KA)	0	0	0	1	0	0
キ (KI)	0	1	0	1	0	1
ケ (KE)	1	0	0	0	0	1
コ (KO)	0	0	0	0	0	1
サ (SA)	1	1	2	0	2	1
セ (SE)	1	1	2	1	1	0
タ (TA)	0	1	2	0	2	1
チ (CHI)	0	1	1	0	0	1
ツ (TSU)	0	1	1	0	0	0
テ (TE)	0	1	0	0	0	1
ヌ (NU)	1	1	2	1	2	1
ホ (HO)	0	0	1	0	1	1
メ (ME)	1	1	1	1	1	0
モ (MO)	1	1	1	1	1	1
ヤ (YA)	0	1	2	0	0	1
ラ (RA)	1	1	0	0	1	0
ル (RU)	0	1	0	1	1	0
レ (RE)	0	1	0	1	1	1
ロ (RO)	1	1	2	0	1	0

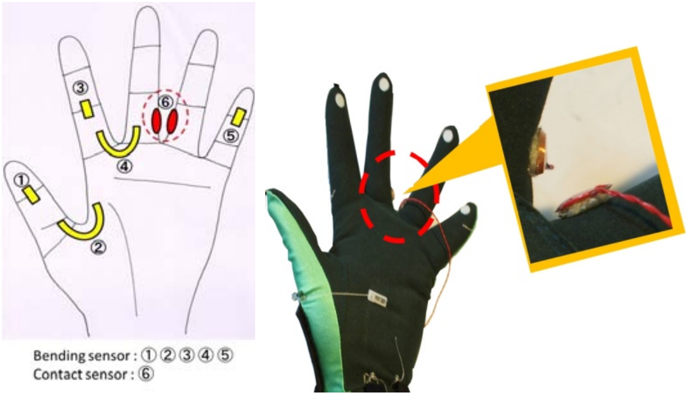

Figure 3. *Sensor Layout(left) and the prototype(right).*

3.2 Results

The prototype distinguished 82% of the given hand postures, compared with the difference between sensor values of the obtained set cover and the measured values of the prototype. Table 2 shows the causes of the errors. The two sensors on ring and pinkie, no.5 and no.6, were the main cause of errors. In addition, the prototype could not distinguish some hand postures; “2” and “3”, “2” and “U”,“CHI” and “TSU”, “A” and “TA”.

Table.2: *Causes of errors.*

Sensor	ratio
no.1	8%
no.2	13%
no.3	10%
no.4	13%
no.5	33%
no.6	23%

3.3 Discussion

The sensor no.5 is the bending sensor for measuring angle of distal interphalangeal joint (DIJ) of pinkie. As the pinkie of the prototype was little bit loose, the slip between glove and pinkie might cause a lot of errors. To overcome the problem the glove should be made of more stretchable material to fit the glove tightly. The same problem happened in the case of sensor no.2 and no.4, which are the bending sensors for measuring the distance between two fingers.

The sensor no.6 is a contact sensor used for measuring the contact between middle and ring fingers. A proximity sensor was utilized as the contact sensor based on magnetic coupling on the prototype. Thus the sensor sometimes misfires even when the distance between the two fingers is not zero. Using a simple switch instead of the proximity sensor may overcome the problem. In addition, it is important to think about also arrangement of a contact sensor to measure the contact between middle and ring accurately. The senor no.6, a set of contact sensor, is put on the sides in opposition each other between middle and ring fingers shown in Figure.3 (right). Thus, the set of contact sensor easily fall from the glove comparing with the other sensors, since they touch each other and catch on the glove fabrics by accident when subjects express hand postures. To overcome these problems, it is also one of the necessary factors to downsize a contact sensor, thought the progress of sensing technology is essential factor to measure a contact state strictly.

The results indicated that the prototype could not distinguish some hand postures, and Table.3 shows examples of the errors of distinction. Figures are the measured values, and figures in parentheses are the correct values in Table.3.

One of the reasons of errors would be simple error of sensor no.4, no.5 and no.6 with high probability. And besides, error of only one sensor causes distinction error in each combination sample as shown in Table.3. Therefore, the prototype has importance to measure hand postures accurately. On the other hand, to add a sensor to the prototype may overcome this problem of not distinguishing these hand postures. For

example, hand posture “2” and “3” have different values on sensor no.5, however, the data of these two were equal to each other this time. Thus, one additional sensor on ring finger may distinguish these hand posture. Therefore, the prototype with fewer sensors than conventional number of sensors will be able to distinguish hand postures exactly. On the other hand, the result shows that the authors found the certain positions of sensor getting error, then the prototype could measure clearly by changing sensor positions of weak reflection, thought it may be difficult to develop the prototype with six sensors.

Another reason is whether each designer can denote target hand postures strictly. Because hand postures are denoted subjectively, they may be given in different ways by different designers. However, this evaluation confirmed that all subjects folded/stretched according to what the table defines, so the difference of subject may not become an indistinctive reason. But it would be necessary to confirm whether the denoted postures are different with each person under an increase of subjects.

Table.3: *Distinction errors of hand postures.*

Posture ＼ Sensor	no.1	no.2	no.3	no.4	no.5	no.6
2	1	1	0	1	1 (2)	0
3	1	1	0	1	1	0
2	1	1	0	0 (1)	2	0
U	1	1	0	0	2	0
CHI	0	1	1	0	0	1
TSU	0	1	1	0	0	1 (0)
A	0	1 (0)	2	0	2	1
TA	0	1	2	0	2	1

The other reason is that the subjects may have expressed hand postures in their own way. A subject told that this hand posture of “A” was different from the hand posture which he always expresses in his daily life. The prototype has been developed to capture “digital” hand postures. Therefore, the slight different between target hand postures and expressed hand postures may give an influence to distinguish these hand postures.

The threshold processing may give an influence with the distinction of hand postures, because the threshold processing classifies data, which bending and contact sensors measure first, into two-bit values and one-bit values, and each sensor of the prototype finally outputs the classified values. The major parameter in the threshold process is a selection of the threshold value. There are many methods to select the proper threshold values like histogram shape-based thresholding method in image processing (M.Sezgin et al 2004), but the prototype utilizes the manually-set threshold values at approximately regular intervals. As the distinction rate of the prototype was 82%, the prototype would use proper thresholds. However, the sensor values of the obtained set cover table were determined by a designer’s subjectivity. Thus, it would be important idea to decide the threshold values in subjective view of a designer. That is, it might be effective method that it compares the measured values of the prototype with the determined values by subjective point of view and chooses the thresholds by using the comparison result. Therefore, the authors will conduct additional experiment about the method to choose the threshold values.

The prototype with only six sensors did not have enough processing function to distinguish 28 hand postures of JSL finger spelling. But, it would be necessary for the prototype to distinguish 28 hand postures by using the values of only six sensors, as it cannot have large number of sensors like the conventional data-glove. And so, the distinction rate would increase if it is possible that the prototype has the function to estimate the correct sensor values with the six sensors.

The result tells that a single sensor measurement error becomes fatal error under the condition with the optimized data-glove as proposed. Therefore, to provide the redundancy to ease the sensor error problem will be the discussion for better manufacturing of data-glove. To make data-glove designing process more effective, a firm algorithm to provide sensor redundancy is indispensable in the future.

Finally, the prototype has a possibility to be used as a command-based input interface for VR system when some postures of JSL are applied as commands, even though it has been developed to measure hand postures of JSL finger spellings. Moreover, as the prototype is developed by using our proposed method to find the minimum number of sensors, the prototype in final version indicates some possibilities to make up a special data-glove for each user. So, this research will be able to make a contribution to data-glove being popular in several kinds of fields as one of glove-type input devices.

4. CONCLUSIONS

The aim of this paper was to make a prototype of data-glove with six sensors and to evaluate whether the prototype can distinguish each hand posture in JSL finger spelling given by users. The developed prototype outputs the bending values and the contact values with six sensors, which consists of five two-bits bend sensors and a one-bit contact sensor, and utilized the existing StringGlove.

The prototype was evaluated in this experiment. The prototype distinguished 82% of the given hand postures, but the prototype could not distinguish some hand postures. One of the reasons, that it fails to distinguish them, was simple error of sensors. The two sensors on ring and pinkie were the main cause of errors. Therefore the evaluation indicates that the improvement of these sensors would reduce the errors of measurement. Moreover, in this experiment, some refinements were found to improve the prototype. By adding the refinements to the prototype, the result indicated that a data-glove with fewer sensors than conventional number of sensors will be able to distinguish hand postures exactly, though it would be difficult to develop the data-glove with only six sensors. However it would be necessary to conduct additional evaluations, to achieve the development of the prototype with fewer sensors to distinguish them exactly.

This evaluation may clear that a single sensor measurement error becomes fatal error under the condition with the optimized data-glove as proposed. Therefore, in the future, a method to provide sensor redundancy is indispensable in order to make data-glove designing process.

Lastly, the data-glove with minimum numbers of sensors would be capable to use as command-based input interface, though the authors have developed the data-glove for JSL Finger spelling, The final version of the prototype could clear that our proposed method to find the minimum number of sensors have an effective method to develop data-glove.

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Camera-based software as a significant tool in rehabilitation/therapy intervention

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ABSTRACT

Use of an affordable, easily adaptable, 'non-specific camera-based software' that is rarely used in the field of rehabilitation is reported in a study with 91 participants over the duration of six workshop sessions. 'Non-specific camera-based software' refers to software that is not dependent on specific hardware. Adaptable means that human tracking and created artefact interaction in the camera field of view is relatively easily changed as one desires via a user-friendly GUI. The significance of having both available for contemporary intervention is argued. Conclusions are that the mature, robust, and accessible software EyeCon is a potent and significant tool in the field of rehabilitation/therapy and warrants wider exploration.

1. INTRODUCTION

A focus of this contribution is applied camera sensing via software requiring non-specific hardware as investigated in a mature body of research titled SoundScapes. In this work, a key focus is on ICT ease-of-use to support end-user/carer/staff/therapist operation via an accessible user-friendly GUI.

SoundScapes is a body of research built upon the author's domestic situation that offered direct relationships to family members with profound disability. In line with this, the research was conceived to explore needs for people with impairment. Investigation of the potentials of alternative intervention strategies using sensors led to the creation of a bespoke infrared non-worn sensor-based biofeedback system. This early system was explored for use in treatment/training/leisure involving natural interaction via residual functional movement for disabled people. The system enabled non-invasive interaction (i.e. gesture-control) of digital multimedia. A prototype system was created for disabled people to improve engagement and participation in treatment/training sessions that were fun and enjoyable yet still rewarding and beneficial to the therapist's goal for development. Game playing and creative expression (making music, digitally painting, etc.) through gesture control was a catalyst of the concept, thus the interchange between the fields of disability, art and games has been active, fruitful and a rich thread to the work. A patented product evolved from the research prototype (Brooks & Sorensen, 2005). The fact that the invention was designed and realised to target disability differentiates SoundScapes from other systems conceived for other purposes, e.g. game playing, dance, music, and subsequently adopted to be used in the field.

Ultrasonic (linear profile) and camera (planar)-based technologies were subsequently investigated alongside the 3D profile IR sensors, both individually and in combinations, due to their different capture profiles. Thus, via an evolved 'mix-n-match' methodology, limitations of one technology are able to be balanced by another so that volumetric/3D, linear, and planar/field-of-view could be selected and combined as appropriate (see e.g. Brooks, 1999; 2004; 2010). This research posits how unencumbered gesture-control of multimedia in rehabilitation intervention is an effective strategy. It also posits how the SoundScapes 'mix-n-match' combining of sensor profiles predates the arrival of contemporary devices that exhibit multi-sensors in a single unit.

Camera-based software as used in SoundScapes is focus for this contribution. However, given the recent adoption of contemporary camera-based video game perceptual controllers in this field, brief reference are included.

SoundScapes investigations highlight how data sensing personalization (input) and responsive content (feedback) tailoring by staff/personnel with limited training requires a suitable interface. Such tailoring

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opportunities are unattainable to traditional facilitators because a suitable interface is missing from many systems. Thus, intervention optimisation is either restricted to those with having technical comprehension or a programmer needs to be employed. The goal of this contribution is to share a software solution that originated outside of rehabilitation yet considering its usability in the field is surprisingly rarely explored as an immediately useable software tool.

'Reafferentation intervention' is a technique developed in SoundScapes (Brooks, 2010). The technique involves the designer/programmer manipulating, during a session intervention, created invisible digital artefacts that can be envisioned as points in space. The points are data-mapped to trigger digital content when 'touched' by a participant. The feedback content stimulates the participant's interactions according to a therapist's goal. An example of the manipulation is a moving of the artefact away from the participant with a goal of extending a participant's movement. The term 'manipulation' is used as the participant is tricked by the technique to not be aware of the incremental extending. This technique is optimal via the Virtual Interactive Space (VIS) that is the invisible gesture controllers' active zone (Brooks, 1999) via artefact interaction. Investigations reported on how such unencumbered interaction was found to be a preference offering increased engagement and participation is sessions resulting in improved outcomes. The MIDI protocol and Max object-oriented programming software was used for mapping selected sensor configuration to content via created simple interfaces. A weakness with the system was that even with such simple interfaces created for therapists and staff extensive training to operate to ensure a comprehension of the VIS dynamic parameters.

2. CAMERA-BASED SENSING SYSTEMS – RELATED WORK

The section illustrates how adoption of 'alternative' camera-based systems in rehabilitation is increasing. Thus, a related selection is made of known work without any disrespect to those not mentioned.

Kizony et al. (2002) reports on the use of a camera-based game system in rehabilitation that evolved from technology originally conceived as a tool for interactive audio-visuals performance. The system tool, VividGroup's Mandala Gesture Extreme (GX) was concluded in a follow-up study by the same group as expensive and requiring an "elaborate setup including a chroma key blue/green backdrop behind the user and bright, ambient lighting" (Weiss et al. 2004). In this study Sony's PlayStation II's EyeToy®, a more affordable commercial camera-based game system, not requiring such a set-up, was favourably compared. However, the EyeToy "closed architecture", preventing system parameter access, was a negative aspect compared to the VividGroup making available a SDK that permitted limited access to the GX system.

Brooks & Petersson (2005), similarly reported negativity regarding access to the EyeToy in a study at two hospitals in Sweden and Denmark with 18 children (in 20 game-playing sessions each) and a control of non-participants with facilitators being two play therapists and three doctors. The study concluded how such camera-based systems that focus on the body as the interface are an under resourced opportunity for therapists to include into training as unlike traditional biofeedback systems there are no attachments to the patient. A reflection was that engagement is optimized through such 'natural interaction' when subjects are 'placed' in the midst of the experience. The resulting hypothesize was that such tools "have potentials to decrease the physical and cognitive load in a daily physical training regime, and this is central to our concept as the child experiences a proactive multimodal state of presence that encourages an unconscious 'pushing of their limits' that they otherwise would not approach outside of the interactive framework. This supports the statement of iterative human afferent efferent neural loop closure as a result of the motivational feedback and feedforward interaction. This process is valuable for the child's physical demands in everyday life as the pushing intensifies the child's experience of movements in practice" (p. 304).

Both the above mentioned systems require specific hardware and a SDK requires a programmer. Inability to access the data, both sourced and content, limits the potentials for any system's ability to be adapted to an individual's need.

This contribution makes the case for user-friendly software that is mature, robust, and affordable. The software enables any standard PC connectable camera to capture data where the field of view is easily accessible for parameter change via a user-friendly interface that allows mappings to content that can similarly be accessed. In this way, flexible tailoring of a system feedforward and feedback can match a subjects' - and therapists' - current requirement as well as offering incremental challenges to match and optimally stimulate progression in treatment programmes.

2.1 *Camera-based Sensing Systems in SoundScapes*

Camera sensing as used in SoundScapes has involved a number of main techniques where common are ease of set up is not required to optimise mobility so sessions are conducted in familiar surroundings for the subject (e.g. no Chroma screen is required as backdrop). The presented software importantly enables (a) the tracking of the human body in the field-of-view, (b) the assignment of dynamic artefacts in the field-of-view that can generate signals when touched, and (c) signals can be easily mapped to open/accessible multimedia. This differs from traditional methods of body tracking where reflective body markers are tracked in the field-of-view of single or multiple dedicated high-specification cameras (e.g. Vicon, Qualasis,…). Marker-based tracking has not been used in SoundScapes due to the preference for systems that do not involve preparation that may unduly stress or tire a disabled participant, instead markerless unencumbered systems are used; however, typically tracking accuracy is reduced.

The Eyesweb visual programming language software (Camurri et al. 2000) originated in Italy for interactive performance and dance. It has been used in SoundScapes and other rehabilitation studies (e.g. Brooks & Hasselblad, 2004; Brooks & Petersson, 2005, Williams et al. 2006) and operates with a standard camera linked to a PC. Both human tracking (including basic skeletal) and artefact assignment/mapping is used in EyesWeb without Chroma screen; it can also map the signals to multimedia and full access is available. However, there is not a user-friendly GUI. Thus, the focus of this contribution is not EyesWeb but rather the aim is to introduce another system that was created in Germany titled EyeCon that enables similar yet alternative and possibly less complex opportunities as EyesWeb. Surprisingly, this software has rarely been used in rehabilitation intervention outside of SoundScapes until recently. As EyesWeb, it also was created for interactive performance and dance; however the body tracking is not skeletal. One main difference in these systems is the user-friendly graphical user interface of EyeCon that is not present in EyesWeb. This interface makes EyeCon an easily learnt adaptable capture and mapping system to content that is accessible to be manipulated. Illustrations from examples of use within the SoundScapes body of research are given from a study involving 91 participants in six workshop sessions in Portugal from 2007.

3. THE EYECON SOFTWARE

The EyeCon software offers access to digital content via a capture and mapping user-friendly interface. The interface uses the camera field-of-view (FOV) as a canvas where lines, zones and other dynamic artefacts can be drawn by the mouse. The artefacts are mapped via the interface to selectable content. Figure 1 illustrates the human interaction with the created artefacts (green lines).

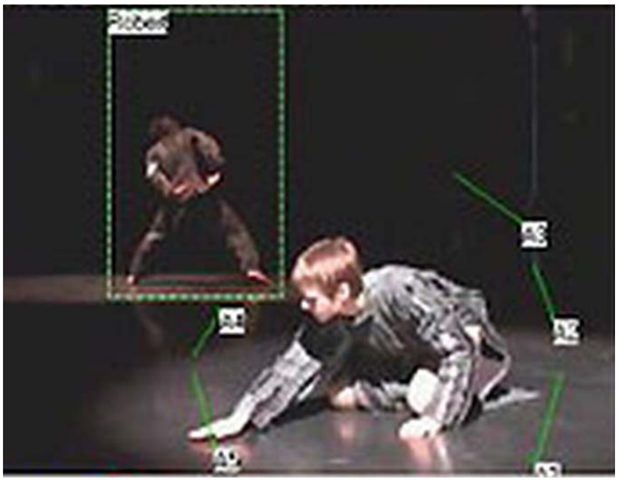

Figure 1. *EyeCon's camera field of view showing created artefacts (green). The female dancer uses her hand to trigger media assigned to line artefact 'A5'. Image © EyeCon.*

Figure 2 illustrates the interface window showing the facility to test mappings with moving circles that activate the media when overlapping the artefacts (the green line, square and triangle).

Each configuration can be saved so a next session can begin where the previous ended to work toward progressive participant microdevelopment. Outputs include: Internal or External MIDI; Direct X systems (Audio Sample player); Windows Media Player (AVI Video); Control of Screen Canvas Effects; OSC message output via Ethernet; all MIDI-standard commands (pitch-bend, volume, etc.).

The EyeCon software was originally conceived for dance and interactive performance. Petersson and Brooks (2007) report use of EyeCon as the core technology around which six workshops focus upon alternative rehabilitation intervention were designed for accessible creative and playful participation involving ninety one attendees. Sixty one attendees were disabled with thirty nine having profound and multiple impairments; an additional thirty were from music teacher higher education. Positive outcomes are reported with the goal of the sessions achieved. Readers are able to access full details via the online archive.

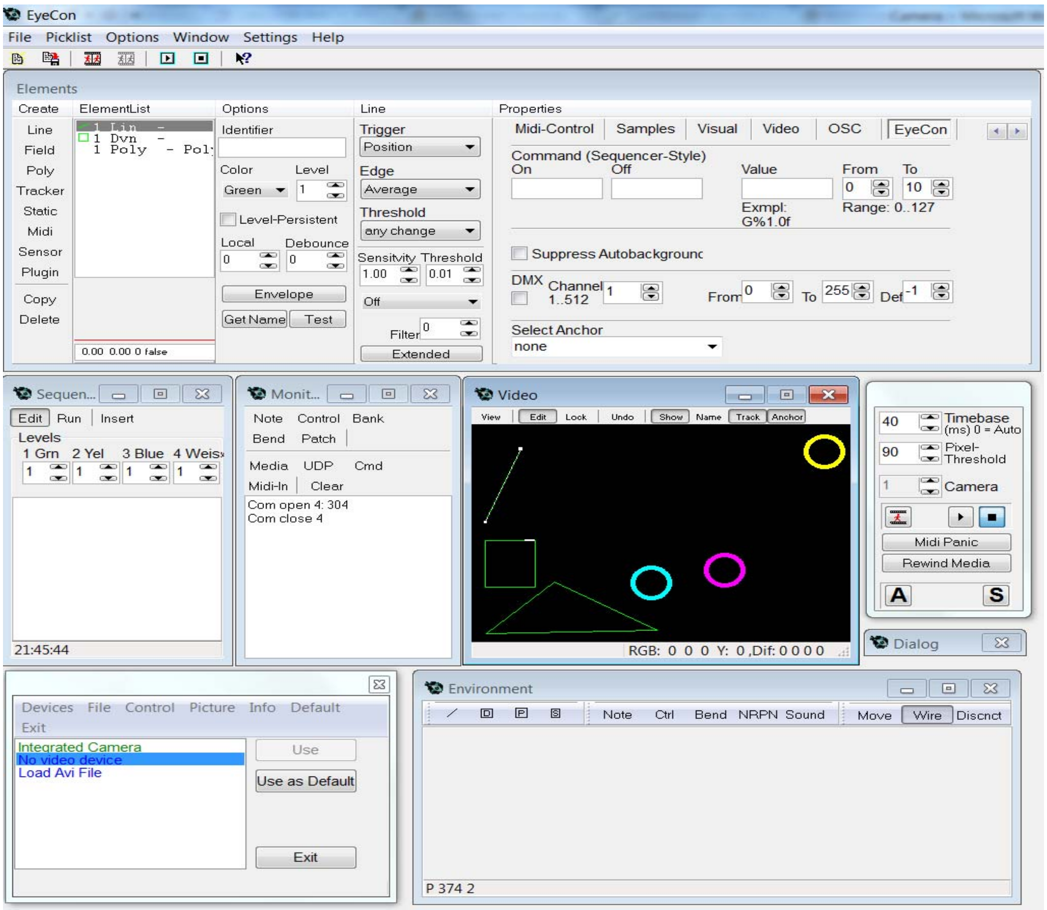

Figure 2. *EyeCon interface window. 'Video' = FOV window illustrates artefacts (green) and test objects. Image © EyeCon.*

Figure 3 and 4 illustrate the use of EyeCon with the participants from the workshop sessions. Video footage from the workshop is also available to view at the open YouTube web site.

4. DISCUSSION

SoundScapes investigates behaviour aspects of interaction with a virtual environment where unencumbered gesture is empowered to control aspects of the computer-generated digital content that constitutes that environment. The gestures that are used to control the environment content are motivated by the interactions and provide data on the user's physical function that in any treatment/training that involves movement can provide significant information to evaluate end-user progress from intervention. An outcome from the SoundScapes research is how such software can contribute to the field by evolving test batteries based upon digital 'measures'. New test batteries using camera-based software such as EyeCon can give quantifiable results of user-progress at pixel level. The complete access to parameter change, both input sourcing and content mapping, is desired for optimal tailoring and this is possible with EyeCon so that incremental challenges of interaction can be adapted according to microdevelopment progress. The context-specific content is used to motivate engagement and participation. In figure 3 from the 2007 workshops, a soccer luminary is used to motivate in the Portuguese workshop due to the high interest in the national sport. The same SoundScapes set up using EyeCon in 2003 was created with Indian cricket players as a part of a two week workshop at the National Institute of Design (NID) in Ahmedabad when the author was an invited lecturer. This use of famous sports personality's images is selected according to the workshop's host country.

User-generated content (UGC) for user real-time manipulation is a strategy also an option for increasing user engagement, motivation, and participation. Figure 4 illustrates EyeCon artefacts and crowd interactions.

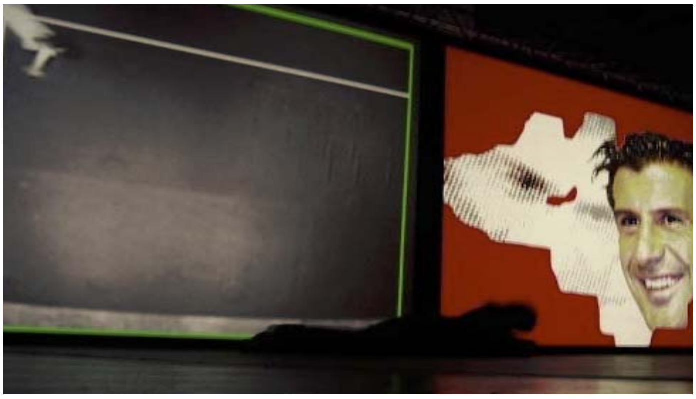

Figure 3. *EyeCon crosshair human tracking – a woman out of wheelchair motivated to move by her motion being captured by an overhead 'treated' camera/lighting mapped to open a mask that originally hid the famous Portuguese soccer star Luis Figo. SoundScapes©.*

Camera-based system stability can be disrupted when image manipulations are involved due to the change in luminosity affecting pixel threshold. Whist the Eyescon interface/software offers threshold adjustment, a technique used in the reported workshops is to use light beyond that which is invisible to the human eye, i.e. infrared, to create some independence of visible light. As certain light-change sources such as projectors, moving head lights, or Hydrargyrum Medium-Arc Iodide (commonly known as Arc or HMI lamps/lights) do not emit infrared the camera can be made totally blind to those light sources. Thus, the workshops were conducted in minimal light conditions for users' focus on the manipulated content. This means that using such projected image content will not interfere with the software.

SoundScapes' critiques may again posit the lack of quantifiable clinical evidence and measured outcome argument because of the alternative approach and unquantifiable results. Such response is predominantly evident from those not having personal acquaintance the research to witness the qualitative outcomes.

The social aspects evoked within SoundScapes are also of importance as evident in the Portuguese workshops example (also in the India workshops). This is exemplified by how the woman in figure who asked to get out of her wheelchair to participate was supported by her colleagues in her progress of the task to uncover who the soccer start was. The aforementioned video exemplifies further with an autistic user.

5. CONCLUSIONS

This contribution focuses upon the 'associated technologies' theme of the ICDVRAT and has an aim to introduce rarely used camera-based software to encourage carers and therapists who may be techno-phobic of ICT supported interventions for rehabilitations. The EyeCon GUI (Graphical User Interface) that is the operational gateway to create invisible artefacts that can be triggered and controlled is a user-friendly entity that encourages exploration. In SoundScapes studies across disabilities, age, and situation, the EyeCon software has shown itself to be a potent tool that can offer significant opportunities and benefits for intervention sessions. This is due to the fact that both sensing and mapping to content is accessible.

It is evident from increased use in researches in the field that camera-based software offers many opportunities in the field of disability and is a significant tool for rehabilitation/therapy intervention. Such software, whether specifically created or adapted for the purpose, is increasingly becoming available through research, open-source and other communities.

The introduction of camera-based game systems, such as cited in this report, support intervention initiatives and are increasingly being adopted in the field of rehabilitation. The biggest impact in this respect is the camera-based Kinect hardware peripheral for the Microsoft X-box that, via the demand for data access, has resulted in a stand-alone (non-X-box) PC version of the hardware alongside software drivers and a designated SDK to enable creative programmers' open access to raw sensor data. SoundScapes attempts to trial as many devices and software as possible where possibilities are envisioned for intervention so as to ascertain pros and cons of each system and to explore mix'n'matching opportunities to optimize useage.

Figure 4. *EyeCon (left screen) plus Eyesweb (right screen) software (split camera feed) - Dynamic zones (rectangles) that are mapped to rhythm music loops and digital painting.*

Evolution of new camera-based solutions based upon the time-of-flight measurement principle (such as used in the Kinect device) are increasingly becoming available that offer adaptive options for use in the field of disability. Strategies of adopting devices that may already be in the end-user's home (such as game peripherals/gesture controllers) also open up home-based training and the use of the internet to communicate results to a therapist in line with Brooks (2004). In line with this is the importance of end-user access to ensure uptake and compliance so that ease of use if a key design prerequisite. EyeCon, as introduced in this contribution, enables access to adapt the data via a suitable GUI. This results in optimum potentials from such systems and is a key focus of the SoundScapes ongoing future work.

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Augmented reflection technology for stroke rehabilitation – a clinical feasibility study

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ABSTRACT

This paper presents a clinical feasibility study of a novel Augmented Reflection Technology system, called TheraMem. The feasibility of the system for physical rehabilitation of the upper limb and the potential to improve motor impairments following stroke were evaluated. Five patients participated in a total of 20 sessions of upper limb training with the system. Tailored support for patients performing the exercises was provided based on the severity and level of their impairment. Various configurations of the system were evaluated and adjusted to best match the patient's preferences as well as the therapeutic requirements. We found that all patients were able to successfully participate and complete the TheraMem intervention. Patients' engagement and motivation was high over the course of the therapy sessions.

1. INTRODUCTION

The use of virtual reality and other forms of computer mediated visual feedback can be beneficial for patients in the therapy of motor impairments after stroke, for the improvements of arm function as well as in activities of daily living. (Laver, George, Thomas, Deutsch, & Crotty, 2011)

Our research group has used computer mediated visual feedback, Augmented Reflection Technology (ART), to fool users about the properties and capabilities of their hands. Users place their hands in two black boxes where webcams video-capture the hands and transmit the video-streams to a computer. These video-streams are then manipulated and displayed on a screen on top of the boxes. (Regenbrecht, Franz, McGregor, Dixon, & Hoermann, 2011) In Figure 1 a sketch of the system is shown as it would be experienced by the patient; the additional screen for the operator or therapist is omitted in this sketch.

Various visual manipulations are possible with ART. The fooling of healthy participants into believing their right hand displayed on the left side of the screen is their left hand was extensively evaluated (Regenbrecht, Franz, et al., 2011). The augmentation with virtual backgrounds or the 3D models in the ART system are also possible. Yet another manipulation possibility is the spatial manipulation of the displayed hand by the therapist or operator, which allows change in the position of the user's hand vertically or horizontally in addition to the user's own movement (Regenbrecht et al., in press).

TheraMem can be described as an augmented reality memory-game. Users move their hand on the floor of the black boxes but experience the video-output on the screen as a three-dimensional environment with 12 tiles on each side of the screen; they try to find matching pairs of plants for the left and the right side by turning these virtual tiles (see Figure 2). The movement of the hand is tracked using a finger-tracking extension specifically added to ART; it determines the position of the hands and flips only the tiles at which the user is pointing at. In addition, TheraMem contains a feature that allows the therapist or operator to amplify the movement of the hand by displaying larger movements on the screen than the user actually performed in the box. The details of this manipulation, the technological background of TheraMem, as well as a detailed study with healthy participants is presented in Regenbrecht, McGregor, et al. (2011).

In this study we use the TheraMem system with individuals with stroke to evaluate two capabilities of ART: (1) the augmentation of the visualization of the user's hand within a virtual environment, and (2) manipulation of the displayed hand movement on the screen. The aim is to clinically evaluate the feasibility of using TheraMem for people with chronic (> 6 months) stroke in a physiotherapeutic setting.

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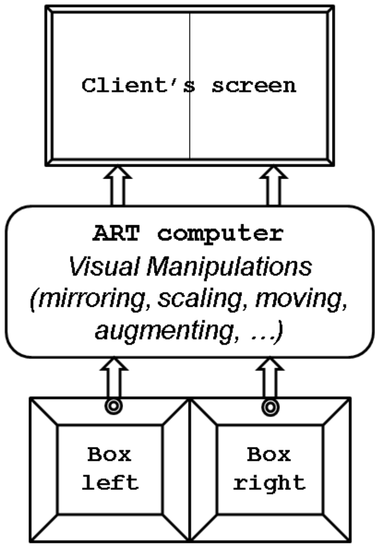

Figure 1. *A sketch of the ART System used for TheraMem.*

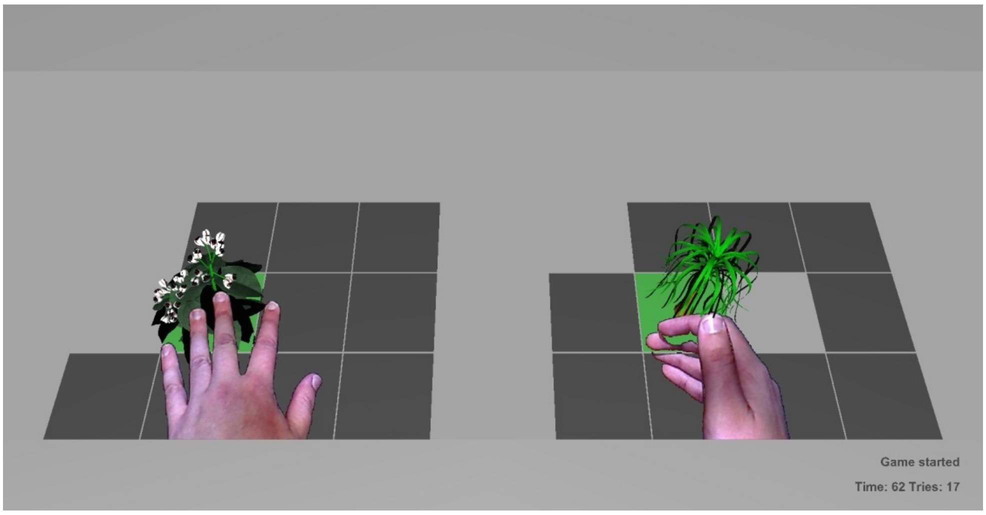

Figure 2. *Gameplay of TheraMem for a patient with an impaired right hand.*

2. METHOD

The usability of the system was evaluated with five people with stroke under the guidance of a physiotherapist and with the help of a system-specialist who operated the system (see Fig. 3). This study was preceded by a preliminary study with two subject-matter experts, in which the protocol was tested and fine-tuned. The two experts, of whom one was a trained physiotherapist and the other a human-computer interaction expert, acted as patients but were actively engaged in providing feedback during the session.

2.1 System & Clinical Setting

The ART system was placed in a local Physiotherapy Clinic. An undisturbed room was dedicated for the entire period of the study. The system was placed in a way to allow a quick change between the settings for left and right side impaired people. This was necessary because the physiotherapist was required to sit at the side of the participant's impairment to provide support if required and to get a better picture of how the participant was performing during the exercises.

The technical operator sat on the left side behind the physiotherapist and the participant. This allowed the operator a good overview and facilitated communication between himself and the physiotherapist without involving the participant too much. Figure 3 shows a picture of the setting for a participant with a right handed impairment.

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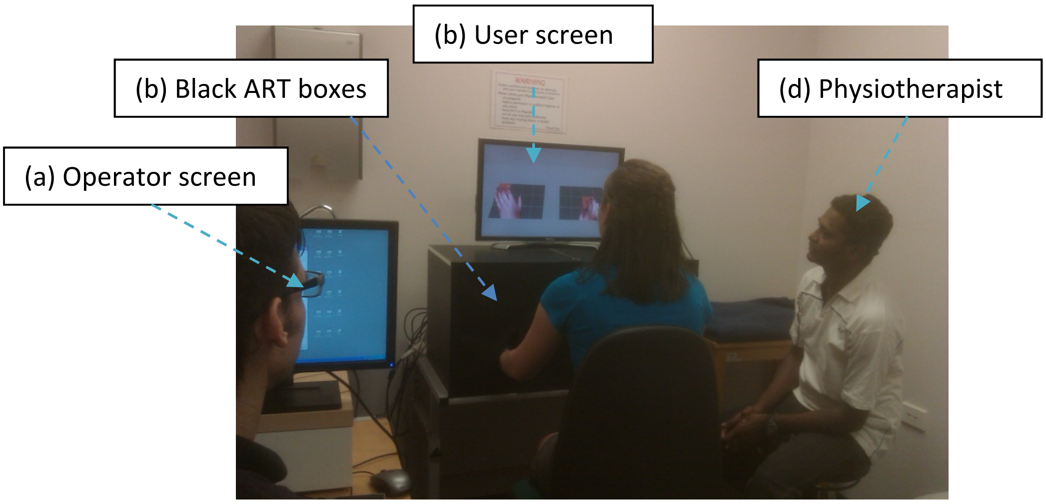

Figure 3. *Clinical System Setup: (a) Operator screen, (b) Black Boxes, (c) User screen, (d) Physiotherapist*

2.2 Procedure and Experimental Design

Hand exercises were administered to all participants at the start of each 60 minute session. For participants with severe spasticity a brief session of warm-up exercises including manual stretching, 'weight bearing' exercises and gentle manual vibration at the shoulder were applied to reduce tightness of the limb.

Each participant was clinically assessed during the first session using the following outcome measures: 1. Fugl Meyer measure for wrist and hand (Fugl-Meyer, Jääskö, Leyman, Olsson, & Steglind, 1975), 2. Motor Assessment Scale (MAS), arm, hand and advanced hand sections (Carr, Shepherd, Nordholm, & Lynne, 1985), 3. Muscle tone assessment with the Modified Ashworth scale (Bohannon & Smith, 1987), 4. Nine Hole Peg test (Mathiowetz, Weber, Kashman, & Volland, 1985). In addition, an assessment of light touch, pain and proprioception sensation in the affected upper limb was undertaken. The same tests were repeated after the fourth session to evaluate the outcome of the intervention. Tests and treatment were administered by the same physiotherapist.

Patients were also interviewed after each trial with TheraMem about their experience with the exercise and equipment. This interview was to explore their motivation and engagement with the technology and what they consider important to change and improve the system settings. After the last session, patients were interviewed about their general experience with the system as well as asked to suggest possible improvements and applications.

2.3 Participants

Five participants with different types of stroke and varying levels of impairment severity of their upper limbs were recruited from the local stroke club. All patients were > 5 years since onset of stroke. A detailed description of each participant is provided in Table 1. All participants gave written informed consent. The study was approved by the Regional Health and Disability Ethics Committee (Otago, New Zealand).

In the initial assessment, three participants scored a total of 0 in both the Fugl-Meyer measure (wrist & hand) (Fugl-Meyer et al., 1975) and the Motor Assessment Scale (upper arm, hand, and advanced hand) (Carr et al., 1985). The other two participants had moderate ratings in Fugl-Meyer and high ratings in the Motor Assessment Scale.

2.4 Nonclinical Measures

The physiotherapist rated the patients' engagement and performance: the ability to understand the instructions, the execution of movements, the participation in activity, the effort, attitude and the acknowledgement of benefits from the participants on a 6 point scale (with 1 being the lowest).

The system-specialist observed and noted technical details, commented on technical problems and asked participants about their experience during the exposure, for example the perceived difficulties and enjoyment experienced.

Table 1. *Participant characteristics at admission.*

Code	Age	Sex	Time since stroke	Cause for stroke and diagnosis	Employment status	Upper limb status
PT0	43 y	F	42 y	Infantile left hemiplegia of unknown cause	Independent, Employed	Moderately impaired, uses affected limb for stabilising
PT1	65 y	M	5.5 y	Right hemiplegia due to CVA	Requires moderate assistance, Retired	Severely impaired. Severe spasticity and deformities involving elbow wrist and hand
PT2	63 y	M	6 y	Left hemiplegia due to CVA	Requires moderate assistance, Retired	Severely impaired. Minimal movements available at the shoulder
PT3	47 y	M	45 y	Right hemiplegia of unknown cause	Independent. Employed	Moderately impaired. Active movement available at all the joints of UE
PT4	53 y	M	15 y	Right hemiplegia due to CVA	Independent. Employed	Moderately impaired. Active movement available at all the joints of UE

3. RESULTS AND DISCUSSION

All participants were able to play TheraMem and complete the game in less than four minutes. The average game time was 190 seconds (range: 120 to 320 seconds); the two less impaired participants were able to complete the game faster with an average of 147 seconds (see Figure 4). Earlier tests with healthy participants (Regenbrecht et al, 2011) reported an average of 134 to 142 seconds; our participants in general were slightly slower. The amount of tries that participants required to complete the game was, on average, 56.4 tries (SD 8.4), which was similar to the 53.5 to 55.6 tries achieved by healthy participants in the earlier study.

Based on the therapist's ratings on patients' engagement, the average was above 5 on a 6 point scale. Accordingly, four of the five participants always found it easy to understand the exercise, demonstrated a very positive attitude towards the exercise, and actively participated in the exercises at their maximal effort, whereas one patient did so only for "most of the time". The two participants with less impaired hands were always able to perform the exercise in a therapeutically reasonable way (demonstrating normal motor patterns) whereas the more impaired participants were "most of the time" able to perform the exercise in a reasonable way but also needed some extra support.

Three support systems were introduced to assist participants with more severe motor impairments in performing the exercise. First was the use of the TheraMem built-in movement amplification, where the performed movement of the participant was amplified so that small movements appeared larger in the game. Second, an elbow-splint was used; it was put on the participants' arm after an initial stretching session and this helped the participant to keep the arm in a relatively straight position. Third, a pointing-device was applied - a wooden stick (tongue depressor), which was given to the participants to hold with their impaired hand to facilitate pointing (see Figure 5). This was necessary because these three participants were not able to keep their affected hand flat on the floor of the box due to muscle contractures / spasticity and were therefore not able to point with their fingers at a specific tile but instead had to use their entire hand to select the tile.

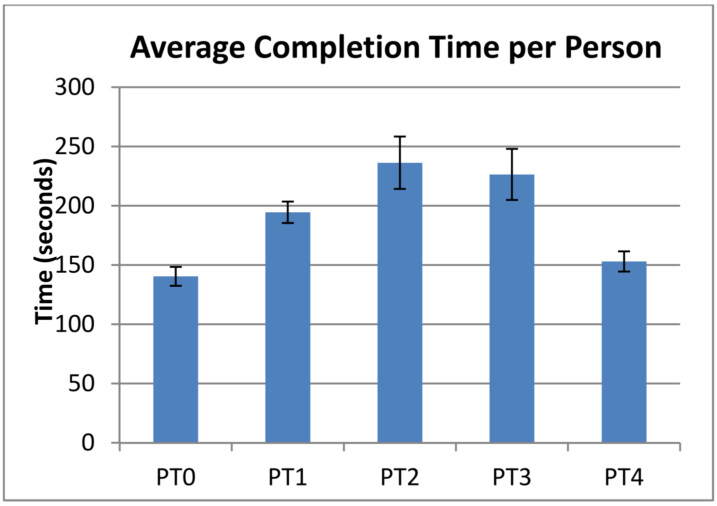

Figure 4. *Average time and std error to successfully complete one TheraMem game.*

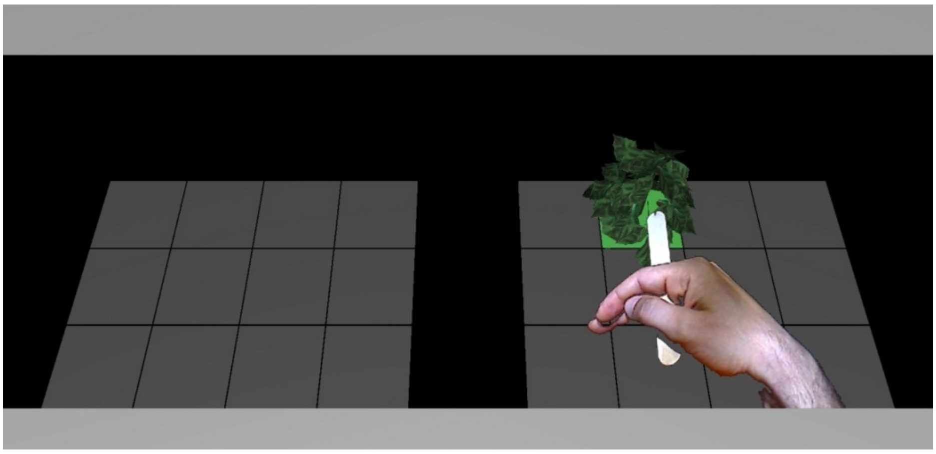

Figure 5. *The use of a pointing-device to support the selection of tiles.*

Improvements in the clinical outcome measures after the last session were found for two participants. These were the participants with moderate ratings in the first assessment. One participant improved in the Fugl-Meyer measure (hand) from 4 to 9 (/14), in the Motor Assessment Scale (upper arm) from 5 to 6 (/6) and in the Motor Assessment Scale (hand) from 3 to 4 (/6). The other participant improved in the Fugl-Meyer measure (wrist) from 7 to 8 (/10).

In the final interview all participants expressed the opinion that the ART system has therapeutic potential for the rehabilitation of motor impairments after stroke. They suggested exercises with the ART system be incorporated in the standard set of therapeutic activities that people with stroke are asked to perform during their rehabilitation phase. In addition, participants expressed their interest in continuing this intervention after the last session. This is especially interesting as two of the participants had not undergone physiotherapy for more than a decade.

The difficulty and variety of the game should be modifiable. Participants, especially the two with less motor impairment, asked for more challenging gameplay. The current setting with 12 tiles, even though the content was randomized after each trial, was decreasingly less challenging for them after they had played the game a couple of times. In addition, participants asked for more variety of games and suggested the use of more and different sets of 3D models "under" the tiles.

All participants felt comfortable and safe in using the system in the clinical environment. In the final interview three stated that they could imagine using the system autonomously without the permanent presence of a physiotherapist and one participant even suggested the use of the system at home. The acquisition of an ART system for the local stroke clubs was also suggested.

4. CONCLUSION

The results of this study showed that the ART system and specifically its TheraMem extension are feasible for use in the rehabilitation of upper limb movement following stroke. The participants were overall, highly engaged and motivated.

The relatively small improvements for the individual participants in the clinical outcome measures were expected and can be explained by two reasons. Firstly, undergoing only four sessions of intervention might not allow enough time for a significant change. Secondly, all participants were in the chronic phase after stroke and therefore the chances and amount of improvement was limited.

In order to evaluate the clinical outcomes, a larger-scale controlled trial with more sessions and a longer intervention period is recommended. In such a trial we would expect larger improvements especially for people who have had a stroke more recently.

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Telerehabilitation for stroke patients: an overview of reviews

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ABSTRACT

The increasing number of survivors following stroke events are enlightening new needs to guarantee appropriate care and quality of life support at home. A potential application of telemedicine is to exploit home care and rehabilitation. Within the framework of an EU FP7 project called Integrated Home Care (IHC) we performed an overview of reviews on the telefacilites for the homecare in stroke patients, in order to plan a clinical trial. A broad literature research was conducted in PUBMED, Web of Science® and The Cochrane Library databases. We included and graded all the reviews matching the following criteria: published in English in peer-reviewed journals, targeting stroke as adult patients (age>18yr.) and considering a homecare setting in the intervention. 6 full-text reviews were included: 1 systematic review with meta-analysis and 5 non-systematic reviews. Despite the absence of adverse effects, no conclusions can be stated on the effectiveness of telerehabilitation compared to other home treatment, due to the insufficient data available, nevertheless strong indications emerged for the inclusion of "all cause mortality" and "hospital admission" as primary outcomes. Besides "QoL", "cost", "adherence" and "patient acceptability" should be included as secondary outcomes, for a complete evaluation of the tele-intervention. This indications should be considered as relevant in planning a telerehabilitation trial, in order to observe the expected effectiveness from a multidimensional point of view in the clinical, financial and social perspectives.

1. INTRODUCTION

The increasing number of survivors following an acute event like stroke and the consequent improvement in their life expectations are enlightening new needs to guarantee appropriate care and quality of life support at home.

The World Health Organisation (WHO) Europe Regional Office considers as a critical issue in Western-countries the fragmented delivery of health and social services.

Disease management has shown great promise as a means of reorganizing chronic care and optimizing patient outcomes. Nevertheless, disease management programs are widely heterogeneous and lack a shared definition, which limits our ability to compare and evaluate different programs. To address this problem, the American Heart Association's (AHA) Disease Management Taxonomy Writing Group [Krumholz, 2006] developed a system of classification (Figure 1) useful to categorize and compare disease management programs and also to inform efforts to identify specific factors associated with effectiveness.

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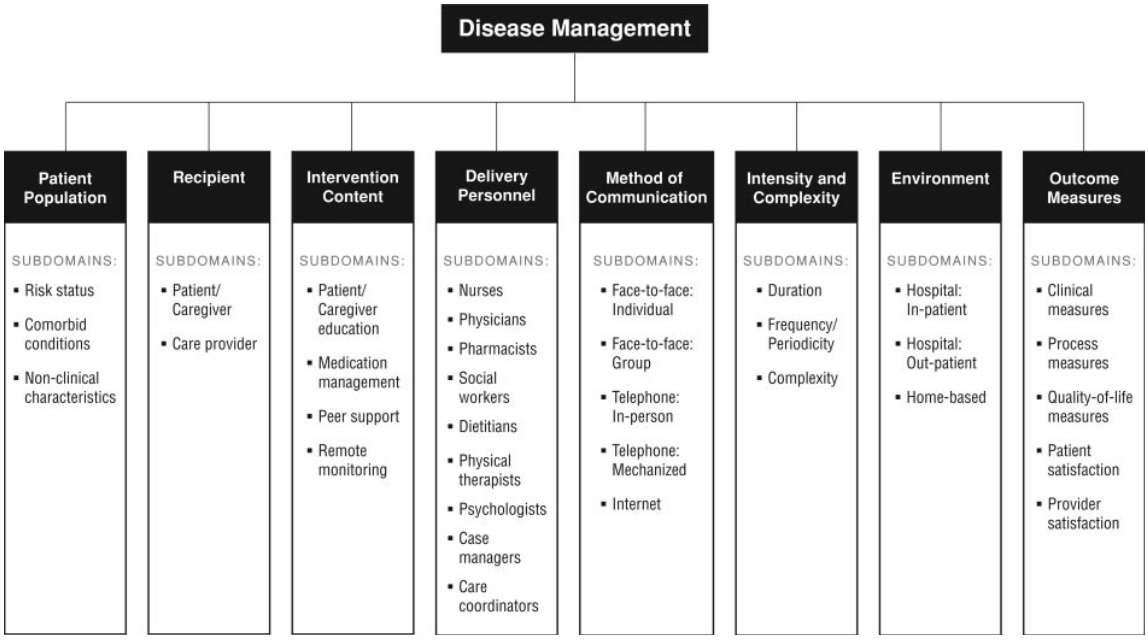

Figure 1. *Disease management taxonomy This diagram appears courtesy of [Krumholz, 2006].*

Following the AHA taxonomy we can defined the telefacilities in homecare with a broader meaning like the "home-based remote monitoring and treatment of chronic patients delivered by healthcare professionals, through internet and communication technologies (ICT), with different intensity and complexity, in order to improve both objective and subjective outcomes".

In recent years, the increasing availability of low costs ICT gave the opportunity to explore the effectiveness of technology solutions in providing health services within and outside the hospitals, with a consequent increasing interest for telemedicine in the rehabilitation/care field, thus the telerehabilitation and telecare are emerging as new branches of the telemedicine [Botsis, 2008].

Continuity across primary and secondary settings is mainly assured by integrated forms of care: telemedicine has been advocated as a possible technological, managerial and economic support for health service integration. A potential application of telemedicine is to exploit home care and rehabilitation of people impaired by neurological diseases such as stroke [Craig, 1999; Craig, 2000].

Telerehabilitation is defined as the remote delivery of rehabilitative services through internet and communication technology (ICT) [Rosen, 2004]. Telemonitoring (patient functioning assessment and clinical management), teletherapy, teleconsultation, telementoring and teleducation are possible provided services directed to patients and mediated by professionals and caregivers.

A number of trials have been published to primarily test the feasibility of telerehabilitation and telemedicine homecare approaches and to compare their effectiveness to standard home rehabilitation/care [Hermens, 2008; Hill, 2009; Piron, 2008; Piron, 2009; Schein, 2010].

A Cochrane review on possible interventions [Currell, 2000] has already explored the effectiveness of the professional practice and health care outcomes in the use of telemedicine compared to face to face patient care, nevertheless the authors couldn't perform a meta-analysis due to the high heterogeneity in the few studies included.

The authors concluded that using telecommunications technologies is feasible, but there is little evidence of clinical benefits, moreover no analysable data exist about the cost effectiveness of telemedicine systems, with a consequent warning for the policymaker to recommend a broader use and investment in unevaluated technologies.

In order to understand the actual magnitude of telerehabilitation benefits and eventual harms when compared to standard home rehabilitation/care and to plan with meaningful outcomes a clinical pilot trial on the tele-treatment at home for patients affected by stroke, we summarized the body of evidence on the telerehabilitation approaches by means of an overview of reviews.

2. MATERIAL AND METHODS

2.1 Search Strategy

To include the major number of papers on telefacilities in integrated care for stroke patients, a broad search strategy, with no limits applied, was run in the databases PUBMED, Web of Science® and The Cochrane Library including the mesh terms: "tele*", "telecare", "telemedicine", "homecare" and "stroke" combined with different Boolean operator.

2.2 Selection Criteria and Analysis

To be included in this overview the selected reviews needed to meet the following criteria.

- language of publication was English;
- the targeted populations must include stroke patients;
- the patients enrolled in the study should be adult, namely with an age > 18 yrs;
- a home care setting considered in the interventions;
- full-text articles in peer-reviewed journals.

The reviews not addressing telemedicine in stroke patients and focused on caregivers or professionals instead of patients directly were excluded.

The included reviews were rated respectively as high, moderate or low by means of a methodological criteria, in order to grade the quality of evidences:

- HIGH: systematic review with meta-analysis
- MODERATE: systematic review without meta-analysis
- LOW: non-systematic review

Descriptive data (author; year of publication; pathologies included; intervention; evidences) was extracted by all the reviews included. The findings were summarized into descriptive tables displaying the main data.

3. RESULTS

The literature search led to 414 potential relevant records in PUBMED (9,4%), Web of Science® (84,6%) and The Cochrane Library (6,0%) (Table 1).

Table 1. *Bibliographic search strategy.*

DATABASE	SEARCH STRATEGY	No OF ARTICLES
PUBMED	tele* AND care AND stroke	39
Web of Science®	tele* AND care AND stroke	350
The Cochrane Library	telecare	5[a]
The Cochrane Library	homecare	7[a]
The Cochrane Library	telemedicine	13[a]

From the overall relevant studies we excluded all those not reporting a review and not published in English, resulting in 49 records whose abstract were screened following the selection criteria. Finally 6 full-text reviews were included in the overview (Figure 2).

The publication year ranged from 2003 to 2006 and the records included comprised:1 systematic review with meta-analysis (16,7%), 5 non-systematic review (83,3%) and no systematic review without meta-analysis. Regarding the targeted populations, the only systematic review with meta-analysis compared different telemedicine approaches with usual care not only in stroke but also in HF patients, while in the non-systematic reviews subgroup all the 5 records were targeted only to stroke patients.

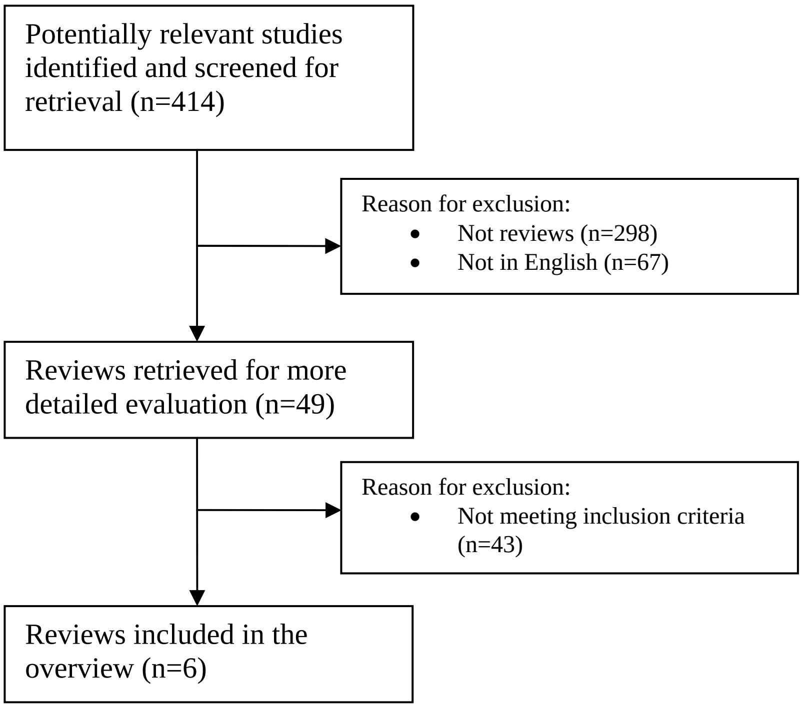

Figure 2. *Flowchart of the publications' selection process. In the QUOROM PRISMA like diagram are reported the detail of exclusion at every step of the review process.*

3.1 Interventions

Different kind of remotely controlled interventions at home were extracted from the analysis of reviews that confirmed the outstanding different approaches to telecare in the management of stroke diseases, after discharge.

It was possible to extract evidences on telerehabilitation interventions for stroke patients intended as:

- telephone follow-up (TFU),
- interaction with devices based on position/sensing technologies,
- remote control of devices based on position/sensing technologies
- remote control and interaction with virtual reality based devices.

Considering the heterogeneity in the different approaches to telerehabilitation interventions, it was not possible to plan a comparison of the results form different reviews.

3.2 Summary of the Evidences

3.2.1 High quality evidences (the study details are reported in Table 2). In HF and STROKE patients:

- Case management interventions providing also TFU were associated with the reduction in the overall mortality in HF patients, especially in high quality study (odds ratio 0.68, 95% confidence interval 0.46 to 0.98, P=0.04), but it is unclear which are the effective components involved in the case management interventions. Moreover TFU in HF and STROKE patients showed clinically-equivalent results compared to control groups due to the low methodological quality of the studies specifically designed for this comparison. TFU couldn't be associated specifically with the reduced mortality in HF and STROKE patients.

3.2.2 Low quality evidences (the study details are reported in Table 3). In STROKE patients:

- The utilization of telemedicine is recommended to increase the delivery of evidence-based stroke treatments.
- There are still insufficient data about the use of telemedicine in stroke prevention, rehabilitation and post-stroke care.

- Telerehabilitation interventions using VR have been improving post-stroke patients outcomes, however few data are available at this time.
- Telemedicine might become a viable option in remote areas
- Developing of a successful implementation of a home-based rehabilitation system is making technology reliable and blind to the user
- Great potential is foreseen if the cost of the system is reduced.

Table 2. *Summary of findings from systematic reviews with meta-analysis.*

AUTHOR	YEAR	PATHOLOGY	INTERVENTION	EVIDENCES
Mistiaen	2006	HF; STROKE	telephone follow-up (TFU)	The low methodological quality of the included studies means that results must be considered with caution. No adverse effects were reported. Nevertheless, overall the studies show clinically-equivalent results between TFU and control groups. Overall, there was inconclusive evidence about the effects of TFU.

Table 3. *Summary of findings from non-systematic reviews.*

AUTHOR	YEAR	PATHOLOGY	INTERVENTION	EVIDENCES
Audebert	2009	STROKE	telemedicine	The utilization of telemedicine is recommended to increase the delivery of evidence-based stroke treatments. In this context, telemedicine can play a critical role, particularly in neurologically underserved areas. There are still insufficient data about the use of telemedicine in stroke prevention, rehabilitation and post-stroke care.
Misra	2005	STROKE	telemedicine	In remote area telemedicine may become a viable option
Zheng	2005	STROKE	Telerehabilitation position/sensing technologies based	Developing of a successfull implementation of a home-based rehabilitation system is making technology reliable and invisible to the user, so that it is simple to attach and use.
Holden	2005	STROKE	Telerehabilitation Virtual Reality based	The field of telerehabilitation is in its infancy, but has great potential, especially if system cost can be reduced.
Burdea	2003	STROKE	Telerehabilitation Virtual Reality based	Telerehabilitation interventions using VR has been improving post-stroke patients, however less data is available at this time.

4. CONCLUSIONS

The state of the evidence emerging from this overview should be considered in planning trials on tele applications to provide rehabilitation services in homecare. Nevertheless it should be considered that the few indications emerging from the summarized data seem to be weak as based mainly on non-systematic reviews.

In stroke patients, it should be preferred an on-line interactive device (allowing also videoconference) than a store and forward device in order to provide the tele-intervention.

Primary outcomes like “overall mortality” and “hospital admission” should be included to prove the effectiveness of interventions; moreover secondary outcomes like “QoL, “cost”, “adherence” and “patient

acceptability” should be taken into consideration to perform a complete analysis of the telecare approach choices.

The above indications should be considered as relevant in trials planning, in order to demonstrate from a multidimensional point of view the effectiveness of telerehabilitation in clinical, financial and social perspective. One of the main issue in dissemination of telerehabilitation mainly relies on the differences in recognizing, by policy maker, this service as a reimbursable one.

Regarding the systematic analysis of the literature, the methodology, in designing studies targeted to stroke population, should improve in order to obtain a more complete framework of the effectiveness of telemedicine as a useful intervention in the homecare of neurological conditions.

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Information and communication technology – a person-centered approach to stroke care

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ABSTRACT

This report describes the possibilities of information and communication technology (ICT) in stroke care, addressing a person-centered care (PCC) approach. Attention is paid to user involvement, design, videogames, and communication between health care professionals mutually as well as with patients, and how to share performance data with an electronic health record. This is the first step towards a supportive ICT system that facilitates interoperability, making healthcare information and services available to citizen's across organizational boundaries.

1. INTRODUCTION

Swedish health care is currently organized much like a production process, meaning that health is treated as a product. Patients are led through a number of routine based procedures and the goal is that they should come out healthy at the end of the process. This method is efficient when treating emergency patients, but less efficient when treating chronically ill patients. For chronically ill patients treatments could become more efficient by being more adapted to particular needs. Since the chronically ill continuously utilize the health care sector throughout their life, gains for this patient group could be substantial (Spegel and Olsson, 2011).

Stroke is a common cause of long-term disability in the developed world (Jones et al, 2012). The person surviving a stroke demands regular personalized rehabilitation according to the individual problem profile and her/his own choice of engaging training activities. The clinically confined rehabilitation is good but worldwide decreasing in time extent. Community or home-based rehabilitation is increasingly looked to as a solution (The National Board of Health and Welfare Sweden, 2011). Upper extremity (UE) paresis is a common problem following stroke and the paretic UE is typically weak, slow, and lacking in coordination and dexterity (Langhorne et al, 2009). Skilled UE performance requires the effective and efficient gathering and processing of sensory information relevant to the task at hand. Research implies that practice on tasks that are automated influence performance and underlie brain activity (Shiffrin and Schneider, 1977), indicating that the premotor cortex plays a role in UE recovery (Johansen-Berg et al, 2002). For the treatment of sensory stimuli in the brain, we have to work out a certain ways in which multiple sensory stimuli, such as motion, visual and auditory information must be coupled. Some studies suggest that video gaming may help stroke patients because of the brain's unusual potential for remodeling, in which it creates new nerve cell connections (Saposnik and Levin, 2011).

The point of departure in the project is with respect to the survivor's continuity of care; the lack of concordance within stroke care. The amount of rehabilitation required to bring stroke survivors to their full

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potential varies across individual cases. Unfortunately the limitations of conventional health care imply that many stroke survivors do not receive the rehabilitation they require (The National Board of Health and Welfare, 2011). In optimizing stroke care in order to satisfy these demands we propose an ICT solution based on communication, shared decision making and therapy. Therefore, empowerment for self-care management through effective engagement strategies (therapy) represents an essential component in this research. It is well documented that poor patient engagement is an important contributor to poor self-care management (Fjaertoft et al, 2011; de Weerd et al, 2011). Thus, engaging stroke survivors as active participants i.e., partners in their own health care will have better outcomes (Ekman et al, 2011). Further, it may take time to adjust with the complexities of being at home to develop stroke survivor's personal resources and strategies (Jones et al, 2012).

The assumption is that such interventions cannot solely be undertaken in institutions but in people's homes, where most of the continuous and daily training actually takes place. Rehabilitation is an essential part in stroke care. In Sweden, stroke care is based on current principles as recommended within the National Guidelines for Stroke Care (The National Board of Health and Welfare, 2009). Inpatient stroke care consists of four main phases:

- Initial presentation, recognition and identification.
- Referral and initial assessment, and recommendations.
- Inpatient rehabilitation, admission, assessment, intervention, discharges planning.
- Discharge and follow-up.

In this paper we concentrate on the third stage, which supports inpatient rehabilitation. The requirement for admission to a specialist inpatient rehabilitation unit in Sweden is determined by the need for an intensive interdisciplinary rehabilitation program that cannot be delivered in an outpatient or community setting, along with the need for nursing care and/or medical treatment. Inpatient rehabilitation is provided by an interdisciplinary team, offering the full range of specialist assessments and interventions. The team includes the following specialist: clinical neuropsychologist, nurses, occupational therapists, physiotherapists, rehabilitation medicine physicians, speech and language therapists, social workers, and administration support. To identify appropriate management strategies to guide stroke care and to coordinate goals and planned activities from all involved actors, a plan of care is usually established. The plan of care is based on needs identified in the pre-discharge stage, a written document which provides an agreement between stroke survivors, their families and health care professional on how to manage day-to-day rehabilitation (The National Board of Health and Welfare, 2009).

The present work addresses the increasing demand on co-operation between different care units, maintaining the continuity of stroke care. Further we wanted to explore the usability of a videogame for UE rehabilitation among occupational therapists (OT's) and stroke survivors.

2. MATERIAL AND METHODS

2.1 Subjects

The study was carried out at Sahlgrenska University Hospital, Neurorehabilitation unit, Västra Götaland County, Sweden. Stroke survivors were identified by occupational therapists (OT`s) working at the Neurorehabilitation unit. OT`s were defined as anyone with a significant professional involvement with stroke survivors as part of their day-today role. A workshop was organized to investigate the perception and technology acceptance of the OT considering gaming for UE rehabilitation. The first two authors gave a brief introduction of the research study through a short presentation followed by an introduction of the interactive videogame, starting from the very basics of the game play.

2.2 System Components

A prototype video game was devoloped for UE rehabilitation, using Microsoft's Kinect gesture control device on a PC. Using its depth, image, and audio sensors, the device translates user's physical gestures into on-screen actions. In the prototype video game players were presented with a series of colored boxes that could be struck using one of their upper extremities (UE). The boxes moved sideways from right to left on a computer screen and when a box had crossed the vertical center line on the computer screen, the box changed color from bleu to red. At the same time as a box (black circle) crossed the centerline a new box would fly in (dotted circle), see Fig. 1. In order to gain feedback (hits) the player had to strike (grasp) the red boxes, i.e. the motion of one arm hitting into the air towards the red box on the computer screen. To acquire hits, the red

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boxes had to disappear, and an alert, hit or miss (voice feedback) appeared. A command line interface was used as the user interface, i.e. typing in commands to start the video game and adjust game parameters.

2.3 *Usability Evaluation and Play Testing*

Information from OT's true interview and usability trials of the prototype game were gathered. Semi-structured interview was constructed to obtain feedback about the subject's perception of the game. It included the following questions. (1) Was the game relevant for OT's? (2) Was the game relevant for UE rehabilitation? 3) Was it easy or difficult to find game information on the computer screen? 4) Was it easy to remember how to restart the game, e.g. after taking a brake e.g.?

2.4 *Design and Development of a Model for a Healthcare Platform for Distributed and Mobile Use within Stroke Care*

A healthcare platform was created with a set of generic care components with a patient-centered approach to support stroke care to improve effective care coordination and quality using a plan of care directly related to management of activities and catching of results of specific activity instances. Hence, the information was structured so that it could be used in different contexts, for different purposes, in the health care process and for monitoring and managing activities. The model reflects the principles as recommended by the National Information Structure (2012) which ensures that the correct information is documented and put into context on the general level (Johansson et al, 2009).

3. RESULTS

3.1 *Usability Evaluation and Play Testing*

Fourteen occupational therapists (N = 14) and four inpatients participated. The prototype was revised during spring 2012. The major problems identified such as how to begin and stop, data entry, continue data entry and label information was found by 80 %. These problems were addressed and corrected by modifying the interface to make the data entry and labeling more intuitive. In general, this usability test uncovered functional and interface design flaw. The OT's and patients pointed out the following criteria as very important:

- Games should have properties that are relevant to therapists and that can be both manipulated and measured.
- Games should target various body movements; it's best if these can be assessed for quality of movement.
- Motor demands of the games should change independently from cognitive demands.
- The game should accommodate both sitting and standing positions.

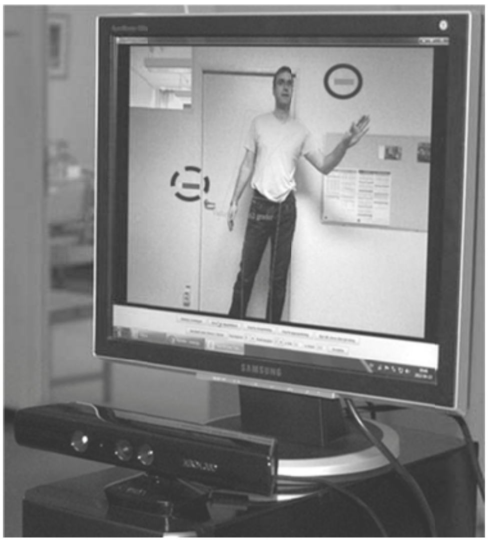

Figure 1. *A screenshot from the player's perspective, in the upper left corner reaching for a red box (black circle) and at the bottom right corner a blue box (dotted circle) flies in.*

Fig. 2 illustrates the user interface with different labeled buttons for retrieving different exercises and record screen activity (top line). Specific instructions for each player to start the exercise were given, “Imagine that there is an invisible button in front of you, now raise your arm and press your hand in the air”. Once the program has seen your hand, it says "Now I see your hand "and a red circle pops up on the screen in front of the player at height of the hand. Should the program lose the hand, it says that "now I do not see your hand anymore”. For the program to see the hand again one has to press the hand in the air again. The program answers "now I see your hand".

Figure 2. *The user interface after the prototype was revised.*

In the second row the user can select game parameters true drop-down lists (dotted box in fig 2), i.e. adjusting the velocity of the incoming box, the number of boxes to be used and on which height the boxes should fly in, see fig.1.

- *Velocity (Hastighet)*. Sets how fast the rectangles to move from 1 – 10.
- *Rectangles (Rektanglar)*. How many rectangles should appear on the screen simultaneously 1 or 2.
- *Y-min*. At the lowest level, a rectangle could fly in.
- *Y-max*. At the highest level, a rectangle could fly in.

3.2 Strategies to Provide an ICT Environment to Support a Patient Oriented Process and PCC Planning

An iterative modeling approach based on different user perspectives, resulted in an interacting model with a structure described in terms of the rehabilitation process for stroke care. The plan of care (Fig. 3) shows activities such as diagnoses, goals, interim goals, planning, assessment, implementation, and timing, use of resources, responsibilities, evaluation and communication. Targeting time priority for activities formulated, each team member has a clearly defined role appropriate to their individual skills. Further, activities can undergo different stages or status changes: proposed; accepted, started, interrupted, or complete. The model developed has its foundation in the individual needs for stroke survivors to high-quality care interventions and professional needs for collaboration between different healthcare professionals and organizational levels.

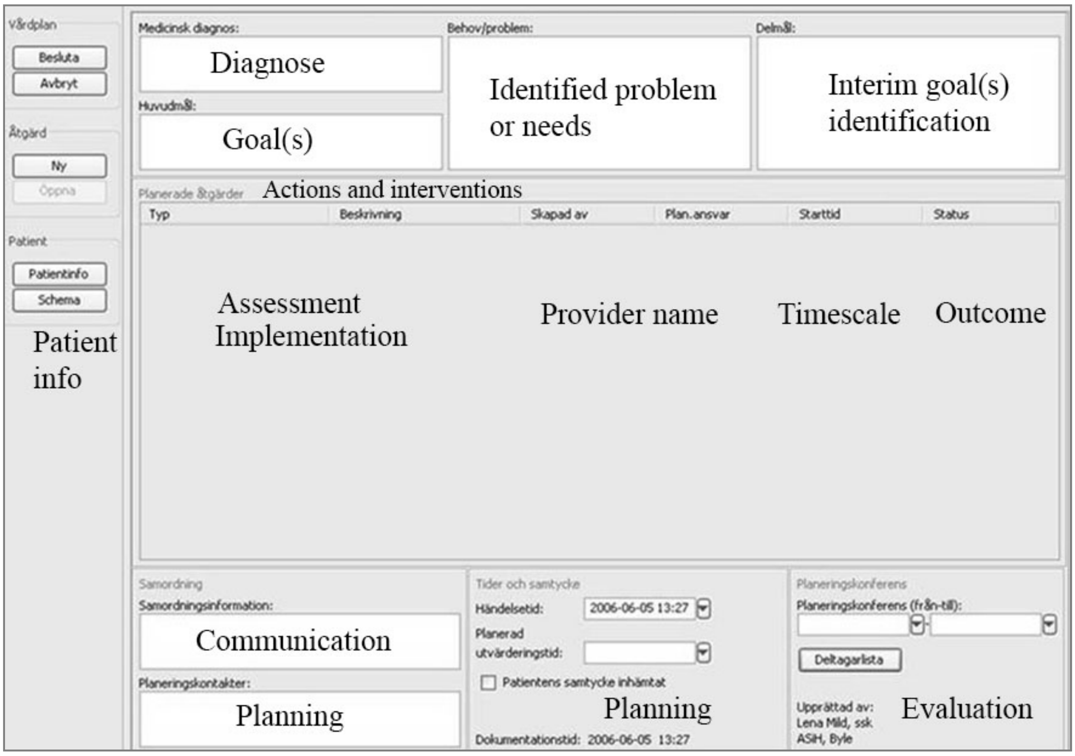

Figure 3. *Screenshot of the plan of care covering health care activities.*

Furthermore, the plan of care can include many efforts over a long period. Each activity leads to some sort of performance that is perceived, interpreted and assessed. Moreover, the use of technical standards allowed us to facilitate data exchange, processing clinical data from the video game into the plan of care.

4. DISCUSSION

An important and central part of this work is user involvement, in this case representing OT colleague in occupational therapy at Sahlgrenska University Hospital. The acceptance level tended to be high. This was in line with an earlier survey among the OT's, although barriers were identified that hinder its use (Haixia et al, 2012). Thus integrating video gaming as a part of clinical practice requires user involvement. Correctly formed design, with adequate user/OT's goals on what can be achieved increases the likelihood that video gaming is used in routine clinical practice. User's goals can be for example that they easily get an overview of certain information or that they will not feel stupid when they use the system. The OT's goals can be for instance the effect on motor function that one would be achieved by placing the videogame in use. Further we focused on improved access as a critical enabler for effective patient engagement. The strategy was to create and collect information along the patient-centered process that included goal relevant activities, i.e. assessments, foresight, individual's condition over time etc. The model provided information defined as in the inpatient rehabilitation process, according to the National Guidelines for Stroke Care (The National Board of Health and Welfare, 2009).

The game is based on motor planning and feedback, i.e. figuring out how to get one's UE to carry out the goal for motor action. Execution is the actual performance of the planned action. The planning and sequencing of a motor task is based on a person's body scheme; that is, an awareness of UE, and how they move through space. The synchronization between movement and sensory stimuli, i.e. reaching for a visual object in which timing, coordination and sensory information is incorporated. Further there is a combination of bimanual task involved. For instance, bimanual training has been shown to benefit motor performance after stroke (Lin et al, 2010). The next step will be integrating auditory feedback and monitoring movements. Recent research suggests that auditory cueing could lead to an efficacious technique that improves movement coordination (Zatorre et al, 2007; Chen et al, 2009). Monitoring movements offers the possibility to record and observe movements. Ertelt (2006) showed that the observation of a movement on a television screen activates motor areas of the brain that have been damage due to a stroke. This seems to have clinical relevance for stroke rehabilitation, because the same area of the brain is activated when a person sees someone else perform a movement that is automated affects underlying brain activity. Neurophysiologic basis for this recruitment relies on the discovery of mirror neurons described by Rizzolatti et al (2004). These neurons discharged when an animal performed an object-related task with the hand or the mouth and when it observes the same or a similar task done by another individual. These results suggest that mirror neurons are involved in the coding of goals through action (de Vries and Mulder, 2007).

The goal was making information and services easily accessible to citizens and to define an information structure that facilitates interoperable, supportive ICT systems with access to information across organizational boundaries. The effective use of resources of complex healthcare data the concept of scalability becomes evident. A scalable system can handle increasing numbers of requests without adversely affecting response time and throughput. Moreover, registry functionality incorporating care plan templates with customizable appropriateness would give the possibility to visualize different care teams and place them along a health-care continuum. A further option would be the ability to have ongoing dialog between multiple caregivers related to an extended process oriented EHR. Gagnon et al (2012) stressed the importance on user involvement as a one of the key factor for successful ICT implementation and that acceptance and resistance are crucial factors in adoption of information system (van Offenbeek et al, 2012).

Since the beginning of the twentieth century we have conducted several research studies on virtual reality technology and telemedicine providing rehabilitating exercises and communications for stroke survivors at home (Rydmark et al, 2002; Pareto et al, 2011). Further we estimated the possible impact on direct health care costs and on quality of life for patients from introducing such a treatment into practices for stroke survivors (Spegel and Olsson, 2011). The results from these studies show that there are possible quality of life gains to be made by introducing such a regime into stroke care.

5. CONCLUSIONS

Increased knowledge in self-care management strategies true participation in shared decision making will enable stroke survivors to take charge of their own care. Through sharing parts of the EHR, information could be used as a teaching tool to encourage patient's engagement and partnership (Frampton, 2008). In this

way advanced technology as movement recognition, exercising in virtual environments, and remote supervision can be used and relate to a PCC process using structured information.

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Second-hand masculinity: do boys with intellectual disabilities use computer games as part of gender practice?

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ABSTRACT

The process of gendered practice in the pursuit of masculine identity is complex with many obstacles and hegemonic forms to negotiate on the journey. Add to this the multifaceted and diverse nature of intellectual disability (ID) and the opportunity for normalised gendered practice is further complicated. Focused on the talk of boys with ID, this paper offers an account of the development of ideas about masculinity to show how gaming may offer a space for gendered practice not available in other areas of the boys' lives. The paper tentatively argues that gaming may offer an opportunity for the boys and those working with them to explore gendered practice safely to facilitate the construction of their identities as men and to challenge problematic images of the hyper-masculine ideal found in these games.

1. INTRODUCTION

The development of a gendered identity, its performance and refinement is a process that both boys and girls navigate to construct ideas about the men and women they will become. Research into masculinity is now an established area of study, but contemporary research considerations of the influence of gender for boys with ID and their developing identities remains limited. There has been no consequent consideration of what methods could be adopted to help boys with ID develop their ideas of the men they wish to become. In contrast the study of male identity has been considered in studies that regard this from the perspective of men who are physically disabled (Gerschick and Miller, 1994; Shakespeare, 1999; Ostrander, 2008). In these studies researchers have established the need for further investigation to consider the interrelationship between masculinity and disability. Gerschick and Miller's (1994) seminal work documents the extents to which men with physical disabilities reframe their masculinity in the face of barriers to inclusion in their communities. This reframing as part of gendered practice can take on a number of forms and aims to emulate or subvert widely held beliefs of how men should be in order to gain acceptance. The contrast of experience between able-bodied men and those with disabilities taking part in the research, is graphically illustrated highlighting that the disabled man is constantly at odds with dominant views of what it is to be a man. However, it is also apparent in research with boys and men without disabilities that the route to manhood is not without its complexities.

It is clear from the mainstream literature with regard to masculinity, that in the process of constructing a masculine identity, dominant or hegemonic forms of masculinity which protect the 'legitimacy of patriarchy' (Connell, 1995), offer a cultural and time specific blue print for men. Within the complexities of this blue print are the constructions of masculinity that are supported and those that are rejected (Connell, 2000). Whitehead (2002) indicates that the existence of dominant and subordinated male behaviour is indicative of the inequalities of gender. However, it would be simplistic to assume that all boys or all men subscribe to a dominant form of masculinity. Unfortunately, for most of these men and boys the existence of the hegemonic form, even at a distance, can be problematic as they navigate their way towards an acceptable masculine identity (Connell, 2000). Frosh et al (2002) in their research with teenagers use a construct of hegemonic masculinities which they and the boys term 'popular masculinities'. This term was utilised to reveal not only the dominance of a particular boy, but also the apparent opposing differences between boys and girls and boys and other boys who did not meet the standards of masculinity required. The location of difference and the dialogue which this creates appears to be an important process in the development of male identity. This view is supported by Swain (2003) who argues that the world of men is governed by a hegemony perceived by boys and that this is supported by visual and print media.

Considering the hegemonic formation of the masculine ideal in this way might lead one to assume that the ideas generated are somehow fixed and impermeable. However, for teenagers constructing normalized identities, place, space and time are influential (Swain, 2003; Archer and Yamashita 2003). Research also highlights the contestable nature of the construction of identity and the battles that can occur in relation to it. Paechter (2003) argues that achievement is dependant on the teenage boy's successful or unsuccessful attempts to project their developing masculine identity on new social situations (Paechter, 2003) Swain (2003) agrees with this position as he posits the physical practice of the body not as something driven by existing notions of 'doing boy' but as brought about through its performance. The challenge remains how best to help boys with ID develop their masculine identity in a safe and effective way.

Virtual reality and its potential for use in the education of people with ID has received some attention over the past two decades (Cromby, Standen and Brown, 1996; Standen and Brown, 2005; Standen and Brown, 2006). Most recently Hopkins, Gower, Perez et al (2011) have demonstrated its effectiveness in improving social skills for children with Autistic Spectrum Disorder (ASD). The use of computer based technology as a tool to assist educationalists in their work with people who have ID is supported for school age children (Langone, Shade, Clees et al, 1999; Mechling, Gast and Langone, 2002; Mechling, 2006) and young adults (Cromby, Standen, and Brown, 1996; Lancioni, Oliva, Meazzini et al, 1993; Brewer and White, 1994; Lancioni, Van den Hof, Furniss et al, 1999;Lancioni, O'Reilly, Singh et al, 2005; Mechling and Cronin, 2006; Mechling, Gast and Krupa, 2007) with ID. Although reporting on small groups of participants, this research shows how computer based technology can be used to improve educational achievement for this group. Little current research centres on children with ID who engage with computer technology not just as an education tool, but through the choices that they make in their lives outside school. However, Orsmond and Kuo (2011) report on the use of computers by adolescents with ASD and suggest that participants were using this by choice and could access it independently.

The purpose of the main study, from which the results for this paper are drawn, was to explore whether boys with ID had a culturally normal idea of what it means to be a boy, what influenced this and what ideas the boys had about their futures as men. This paper will focus on the boys' use of games as a potential space for gendered practice and their experience of second hand masculinity via the hyper-masculine characters typically found in many commercial games.

2. METHOD

2.1 Participants

A qualitative methodology was adopted to elicit the views of participants with an ID about their lives as boys. Twenty one boys (see Table 1.) who were engaged in a process of transition in years 8 to 11 were recruited from a school for children with special needs. Consent was gained from the boys themselves and from their parents.

Table 1. *number, year group and age of sample.*

Number of participants	Year group	Age of participants
3	8	13-14years
6	9	14-15years
4	10	15-16years
8	11	16-17years

2.2 Procedure

The primary researcher initially spent six weeks in the school observing the boys and preparing materials for the group interviews. Participants were divided into five groups based on their age and friendship group following guidance from the boys themselves and teaching staff at the school. Each group took part in a sorting exercise as described below and then each individual was asked if they would like to progress to individual interview. Of the 21 participants 4 were either not interviewed as a result of their ability to engage with materials in the group interviews (n=2), or did not attend for interview at the time arranged (n=2).

2.2.1 *Group interviews.* First group interviews were conducted involving the boys sorting images of men doing various activities. The development of the bank of images used in the group was informed by the work of Frosh et al (2002) and the earlier observations made by the primary researcher. Groups were asked to sort

the images into two piles: images that the boys did not support as masculine and images they did support. Conversations between the boys while negotiating decisions were digitally recorded and transcribed verbatim prior to analysis.

2.2.2 *Individual interviews.* Boys were asked, during art classes as part of the school timetable, to produce in a medium of their choice visual representations of their predictions of their lives as men. These were then used in the interviews as a trigger for discussion. Interviews were digitally recorded and transcribed verbatim ready for analysis.

2.3 Analysis

Using NVivo 9 to store and organize the transcripts, a constant comparative method of analysis was used following each episode of data collection until saturation was achieved. Six themes emerged from the analysis of the group and individual interviews supported by a seventh overarching theme which emerged from the participants' view of themselves as *'The way we do boy'*. One of the six themes which emerged from the boys' talk about the lives of others was Vicarious (second hand) masculinity. This theme has two threads; the first identified the boys as looking on, experiencing constructs of masculinity through the lives of other boys and the men in their lives; the second, which forms the focus of this paper, illustrates the boy's lives through the computer games that they played.

3. RESULTS AND DISCUSSION

The scrutinized lives of the boys who participated in the research and their deep sense of being regarded as other became a focal point when conducting both the focus groups and individual interviews. Boys were eager to talk about how they conducted their lives as boys, in a very tangible and celebratory account of boyhood from their perspective. Expressing a credible account of boyhood in poignant and playful ways was an essential part of their talk. Boys were careful not to frame their accounts in the context of difference or allow their ID to dominate their accounts of their masculinity. The time spent in the school developing and then conducting the research resulted in interesting exchanges when the boys would exclaim *'you've seen us!'* This was used to remind me of the time I had already spent with them watching them play football, engaging in computer gaming and participating in curricular and non-curricular activities. An alternative and equally credible explanation of this could be that *'you've seen us!'* was an expression of the ever watchful eye of adults in their lives. So aware of being watched and scrutinized in all areas of life, the boys may have assumed that I was fully aware of everything. Interestingly the only aspect of their lives that could not be scrutinized in this way was their interactions and activity in the virtual world of games.

In their exchanges with both me as researcher and other boys, participants spoke of their games consoles and how gaming was essential to the construction of their identities as boys. Used in part by the school as a reward for the completion of academic work, gaming was also valued by the boys as an independent pursuit free of the restrictions of others. In the virtual world, inhabited by their favorite characters, the boys could be successful and heroic, achieving beyond what would be expected of them in the real world. The analysis of both the focus groups and individual interviews appears to suggest that the boys used games as a space for gendered practice and also as an opportunity to experience second hand a construction of hyper-masculinity through characters in console games.

3.1 Games as Space for Gendered Practice

In the school opportunities for gendered practice were limited as the school day was framed not only by the curriculum but also by the ever watchful eye of adults, who controlled both classroom areas and communal spaces. However, it was clear to the boys with ID that virtual spaces were relatively un-policed by others and could be easily accessed and some spent as much time as they could in these spaces:

Philip: Football, yesterday I played...oh was it yesterday? I think it was yesterday I played cricket on my play station. I played on my PSP on the bus yesterday and...

These ideas about the significance of accessibility are echoed by another boy who describes his strategy for ensuring that he has the latest console to play games on. Cost is not an issue only that it is available and that access is assured.

Ian: Yeh, and then I had to go on E-Bay and get My PS3. So I'll be doing that with my PS2 then when I get my PS4.

Int.: So you keep your PS3 and you get your new PS4.

Ian: Yeh. Well the PS3 will be down stairs though or I might give it to my brother.

The fact that the PS4 was then and is not yet available is not important here. Ian's ideas to keep those things he loves close to him and accessible are part of a plan to maintain this in his life. The knowledge Ian possessed regarding gaming and the gaming world was incredible and he often acted as a source of information to other boys on the next game coming into the shops.

The subordination of masculinity on the grounds of ID was a regular experience for the boys.

Chris: These fights, you know these bullies at (names mainstream school) they had a fight with me, I just… and all the time I get into trouble. And you know the other time right in this lesson I accidentally wacked my hand on the teacher's face like that.

John: You accidentally wacked them on the head?

Chris: Yeh I did because (names two other boys), those two dimwits got me into trouble and they had to put me out.

Yet in the virtual world they could be dominant and competitive without fear of reprisal from others. Solitary games gave boys the assurance that their success, or lack of it, was a matter for them and could not be compared with other areas of their lives or referenced by their ID. Growing confidence opened up an opportunity for one teenage boy to explore gendered practice as part of an online gaming group. The virtual world became a space for spontaneous engagement with others, where intellectual ability was not a pre-requisite to inclusion as was apparent in other areas of the boys' lives.

John: Yeh, I do play those a lot of the time as well as others.

Int.: Do you play it on your own, or do you link up with people over the internet?

John: Well, as in the World of War Craft I can play with other players at an instant.

Int.: Right?

John: So I just Log in and there's all those people that you've got you can't go on single player mode now.

The immediacy of contact between John and others is clearly appealing. Talk centres on unfettered access and a joining of equals. The assumption is that ID is unimportant or in recounting the events in the virtual world it is not important to focus on difference. John uses this opportunity as a springboard for testing out a way of being in what he regards as a safe environment.

John: Well we do have our little chats about what's...we don't say like what our names are and everything.

Int.: No?

John: Or where we live, we just talk about things, about like what we should do on this certain place. Or, like we talk about, really complain about stuff that is really annoying on the game and everything.

Enthusiastic talk about solitary gaming or joining with others as part of a virtual world was common among those interviewed. In particular the anonymity appeared to suit the boys and gave them the opportunity to try out ways of being male that was not available to them in other areas of their lives. For those joining with others in virtual spaces to play games, this appears to help draw them away from their embodied identity as intellectually disabled, giving a sense of a gendered identity equal to others. The need to maintain this as an opportunity for the *way we do boy* also emerged in talk about age limits for gaming.

John: It is quite interesting playing it still you can still...the game that I'm playing right now you can play at a certain age, but I had someone which was 106 playing once.

Armed with this sort of information, perhaps slightly exaggerated in the account, boys could argue for gaming to be part of life well into adulthood and eventual old age. Talk of others' involvement in gaming also helped to strengthen boys' accounts of gaming as a space for gendered practice.

Simon: Shall I start with my dad's?

Int.: Yes please.

Simon: Sega, sega advanced a play station a play station 2 and a Wii and when my step brother comes we got a X-box 360 as well and a play station 3.

The maintenance of gaming as an opportunity for boys was also supported by the school and became a focus in talk regarding making the transition from the main school to provision for 16 to 19 year olds known in the school as the 16+ unit.

Int: What's good about 16+ and staying on?

Simon: You get money.

Int: You get what? Oh you get some money (Education Maintenance Allowence (EMA)). I can see a theme here Simon! (Had talked about making money when older, winning the lottery was a favourite).

Simon: No, no, no, you don't get money. It's like there's games...a play station 2 and X-box 360 and play station 3, in that big room.

Int.: OK.

Simon: No not the big room just the one you see people in.

Philip, John and Simon's accounts give a position for gaming in their developing ideas of their gendered identities. Although John's account is slightly different in that he joined with others to play games, the dominant factor is the boys' desire for autonomy and independence through an unrestricted medium for testing how to be boys without the complication of disability.

3.2 Games as a construct of hyper-masculinity.

Those interviewed enjoyed the experience of being part of a world populated by hyper-masculine characters where they could be a successful cricketer one minute and a superhero the next. Gaming gave the boys a great deal of excitement, escapism and a sense of anticipation as they wondered what might happen next in their virtual worlds. Games equated to living a more exciting life through the embodiment of hyper-masculine characters.

Ian: I've finished Ironman.

Int.: Oh have you?

Ian: Yeh. So I've got to wait to get the Incredible Hulk now.

Int.: Yeh? So you like things that are real action that you have to work through.

Ian: The Black Knight's coming soon as well.

Int.: The Black Knight? What's that?

Ian: Batman.

Favoured characters populated games which included sport, superheroes or the anti hero (villain or criminal). The un-problematized representation of the hyper-masculine and the actions of characters were particularly attractive to the boys.

Andy: The action and the adventure.

Int.: Yeh?

Andy: Stuff like that. Sword fighting games.

Int.: Sword fighting games. Are they your favourite?

Andy: And shooting games.

Preferences were often underlined by those interviewed.

Andy: I've got some fighting games. I've got Prince of Persia, South time for the PS 2, halo 2 for the X-Box, for the normal X-Box, and I'm hoping that I might get my X-Box 360 to get Halo 3 and Assassins Creed.

The types of characters in these games are tough and in control of their destinies, something that the boys admired and wanted to emulate.

John: 'cause there's different areas with as many people and you can join up with them as well. So I was in this instance and all of a sudden this creature we killed it of course and then something happened it just went off and then on and then she was there again and of course we were at full house so we had to kill her again. It just kept on happening so we had to run out of the instance and reset it all and everything.

Later on in the interview John describes another occasion when those on line had to collaborate to fix a problem.

John: There was like two dead bodies there when we came back and then we went there again it didn't happen again but with other ones it did and we were quite annoyed at it. We weren't annoyed 'cause we got extra things with it, but we were annoyed that it actually did happen when we were resting and everything.

Talk of success and dominance over others was something that was in stark contrast to the lives of the boys in the real world.

These findings raise interesting issues regarding the boys' developing identities and their masculinity. Time spent using computers appeared to be driven by the boys' enthusiasm for games and the opportunity to engage in activities independently. Similar to the view of Orsmond and Kuo (2011) who suggest that although solitary, computer use by people with ASD indicated independence, the boys were able to control this for themselves free from the interference of the adults in their lives. The development of independence and control by the boys differs from the finding of Foley and McCubbin (2009) purely as a result of the lack of external control over how they used the computer and what games they played. It could be suggested that this independence and control could be linked to gendered practice and that the boys, who lacked opportunities to try out aspects of dominant forms of masculinity, were using computer gaming as a conduit for testing this out.

The effect of gaming on the boys' persona is another aspect that should be questioned as a result of these findings, particularly as they favoured games that allowed them to embody hyper-masculine characters. Although changes in the perception of violence could not be identified in this study as in Deselms and Altman (2003), it could be argued that games played by the boys strengthened ideas of power and control as aspects of masculinity. In addition, the hyper masculine characteristics of male characters in the games and the boys' view of them may be problematic in the development of future ideas of gender roles as found by Dill and Thill (2007) in their research with teenagers. However, these games may offer the opportunity, as part of a clear strategy, to help the boys to question both desirable and undesirable aspects of masculine identity. Although the images of men and women in the games are problematic (Burgess, Stermer and Burgess, 2007), the games may offer a way of challenging thinking about masculinity and the objectification of female characters that engages the boys in a medium that they enjoy. The practice of popular masculinity in the work of Frosh et al (2002), in which they offer 'hardness' as a representation supported in activities with other boys, may offer opportunities for working with boys with ID who enjoy gaming. For the boys with ID in the study this could mean testing out their experience of being 'hard' or tough through the computer games they play. The image of the lone assassin roaming the virtual world in search of his next victim is a representation of toughness that could be successfully achieved by any of the boys in the study. Hardness could be indicative of successes on a virtual level, offering equality of access to the world of boy and eventually the world of men. The challenge would be in working alongside boys with ID to help them analyse the representation of masculinity in the games and contrast that with the reality of their developing gendered identity.

4. CONCLUSIONS

The narratives developed by the boys in the sorting exercise and interviews offer an invaluable insight into their lives. Through their talk the participants have given form to *the way we do boy* in the school and the experiences, changes and influences that have and continue to shape this. The boys' insights are illustrations of their lives now, but also offer a glimpse of how they wish to shape their lives as men in the future. Their understanding of themselves and their interpretation of the lives of others, although referenced by limited experiences, paint an extraordinary picture which brings both opportunities and restrictions into sharp relief.

Gaming is an important part of the boys' lives and is perhaps indicative of a developing independence and control not available to them in the real world. Through the boys' talk their enthusiasm for the games is clear and solitary games offer the opportunity for freedom and a chance to practice aspects of gender identity. It is suggested that the engagement with games by boys with ID can be used to widen their opportunities for gendered practice and question aspects of dominant masculinities including their construction. Further research needs to be carried out to establish how boys with ID use games and if these are in fact influential in the formation of gendered identities.

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Using virtual environments for trigger identification in addiction treatment

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ABSTRACT

This paper presents a novel application of virtual environments to assist in encouraging behaviour change in individuals who misuse drugs or alcohol. We discuss the background and development, through user-led design, of a series of scenes to engage users around the identification of triggers and encourage discussion about relevant coping skills. We then lay out the results of initial testing of this application that showed variation in responses but, on average, the system encouraged discussion around the topic and was linked to a mild improvement in the users' confidence in the subject matter of the session.

1. INTRODUCTION

Computers, games and other forms of interactive technology have the potential to offer new ways of reaching people who misuse drugs or alcohol. An estimated 306,150 people misuse heroin and crack cocaine in the UK (Hay et al, 2011) and an estimated 1.6 million people in England are alcohol-dependent (Department of Work and Pensions, 2010). Very few of those affected ever engage with the support they need with only 56.2% of drug users (Roxburgh, 2011) and 6% of alcohol-dependent individuals (Ward, 2010) accessing support. This leads to negative economic, social and health impacts. Even when people do engage in treatment services, there is a high rate of relapse. It is estimated that 40% to 60% of those completing treatment will relapse (NIDA, 2009). This has long-term cost implications with the cost of drug and alcohol misuse in the UK estimated to be between £20 billion and £55 billion (NICE, 2010) annually.

Triggers are the objects, people, and situations that lead to craving, and they play a big role in relapse and prevent people from reducing their use of substances. Triggers can include a wide range of things including triggers directly related to a substance (such as the substance itself or other related paraphernalia), stressful situations or interpersonal situations. Teaching people about these triggers and the ways they can deal with them can boost people's chances of recovery and avoiding relapse. This paper investigates a game-based system to support people in identifying their triggers as a part of developing coping skills.

2. RELATED WORK

The use of interactive technology in the treatment of addiction has been previously investigated in a range of contexts. Many of these are computerised versions of more traditional interventions such as brief interventions, where people are assessed and given initial information and encouraged to engage in a more in-depth manner, and Cognitive Behavioral Therapy (CBT) which uses a systematic, goal-orientated approach to treating problems.

Exposure therapy is another real world treatment that can be utilised by computer based therapies. It is a process in which the patient is exposed to situations to provoke a reaction relating to the disorder they are in treatment for. This enables the therapist to help the patient identify triggers for their behavior and develop coping skills. Studies (Martin, LaRowe and Malcolm, 2010) have found exposure therapy in the real world as effective as other addiction treatments but highlights issues around practicality and costs. Additional costs are

incurred by the need for exposure therapy to take place in multiple locations (Conklin and Tiffany 2002). Virtual Reality could allow this to be more practical and cost effective without exposing the service user to a potentially risky, uncontrolled environment.

Online brief interventions have been used to identify at risk individuals as effectively as trained staff, allowing more people to receive brief interventions with less staff time (the primary cost in delivering brief interventions) (Bewick et al, 2010). Similar CBT based systems have had similar results. One such study found the computerised system achieved similar results to existing face-to-face approaches using an eighth of the staff time (Marks et al, 2003). These show that desk top and browser based interventions can be effective, engaging and appropriate.

In addiction there has been less study of the use of Virtual Reality Exposure Therapies however experiments have shown that craving can be triggered by virtual cues for smokers (Bordnick et al, 2004), alcohol users (Bordnick et al, 2008) and those who use cocaine (Saladin et al, 2006) indicating that the users respond to, and hence can be taught to identify, triggers in a virtual scene.

Exposure therapy is not the only potential avenue for exploiting VR technology in treatment, as one study into the therapeutic value of crushing virtual cigarettes shows (Girard et al, 2009). Participants were assigned to either a virtual environment where they found and crushed cigarettes, or to a neutral control environment. Those in the control group had a higher drop-out rate from the programme and less reduction in tobacco use. The authors suggest that this may show that the experimental group was more involved, had a higher level of motivation and reinforcement due to the crushing of cigarettes, which conditioned them to feel negatively about them, or had learnt to associate feelings of immediate success with the removal of cigarettes from their environment.

Video game technology (Gamberini et al 2009) was used to engage young people about drug-related issues. The game's narrative is user directed showing the consequences of their actions and presents relevant information. A survey of users found that the game was well received and was considered to be a reliable source of information; however there were issues around the lack of customisation available. No information was recorded on the user's craving or willingness to take drugs which leaves questions over its suitability as a behaviour change intervention.

Approaches used in other areas of mental health are also of relevance. Coyle, Doherty and Sharry (2009) developed a game to teach adolescents Solution Focused Therapy (SFT) skills. The game is played by the patient whilst the therapist oversees their progress and engages them in conversation around subjects that are brought up. The paper shows promise for the system, with clinicians feeling it was helpful or very helpful in engaging participants around the topic of SFT in 86% of cases. This shows that games can facilitate positive outcomes in a traditional therapeutic setting.

Reach-out central (Burns et al, 2007) works within a similar area. The game aims to engage a hard to reach audience, teenagers, around mental health issues. In the online game users become involved in a series of storylines relating to common problems and issues facing teenagers. The game, backed by a media campaign, was successful in engaging and influencing users. User feedback (Shandley et al, 2010) highlighted the need to engage users through early goals and direction, the need to offer a level of personalisation, focus on the most relevant issues and the need for the problems facing the user to not have a clear "right" answer.

In "*The Warriors' Journey*" (Morie, Haynes and Chance, 2011) narrative therapy (the exploration of issues and events in one's life through story telling) is used to help returning soldiers deal with any anxieties or difficulties arising from their return to civilian life. A second life based system engages users through a narrative that establishes the recurring themes throughout different forms of military service, and the associated stresses. The user is then able to engage in building their own narrative to reflect their experiences. This is intended to encourage a sense of self esteem, a feeling of control and provide a gateway to restructuring their life narrative and the achievement of a more positive outlook on life.

Virtual Reality exposure therapy has been found to be as effective as a real world equivalent (Emmelkamp et al, 2002 and Difede et al, 2007) in areas such as phobias and Post Traumatic Stress Disorder. This shows that there is therapeutic potential for this sort of technology.

3. OBJECTIVES

We have developed a simulation based VR application that comprises an exercise to identify potential triggers for craving within a series of virtual scenes. The application is being tested in a group programme for

people recovering from drug or alcohol addiction misuse issues. This research will investigate the following questions:

- Can virtual scenes be used to help service users learn skills to identify the triggers for their cravings?
- How does the virtual version compare to the real-world version of the activity in terms of user engagement and reported learning?

We hope to also provide insight into the following secondary questions.

- Does this technology stimulate greater levels of discussion and group work within a structured day programme setting than the existing activity?
- Do users feel engaged and immersed with this sort of activity?
- How can service users be directly involved in the development of games to teach coping skills?

The novelty of this research arises from several areas. The use of technology as part of the treatment of addiction has not been widespread in any format so far, particularly in a group setting. This research will also examine the delivery of a format of intervention, teaching users about identifying triggers and their patterns of behaviour, that has not been the focus of previous research.

4. APPLICATION DEVELOPMENT

4.1 The "Spot the Triggers Challenge"

The initial stages of this project involved consultations with end-users to identify and develop potential means of embedding interactive technology into services. This started with focus groups to identify and assess concepts for activities and tools that could be provided. One of these was a simulation to aid users in identifying, understanding and coping with triggers and cravings. This paper focuses on how this idea was extended and developed from this initial concept into a functional prototype.

The project involves developing a game to encourage learning by allowing users to take part in a virtual reality based task about their triggers. Within the game users navigate around virtual scenes containing a variety of potential triggers and are tasked with identifying the triggers in the scenes that are relevant to them. These triggers are then stored and used as the basis for other tasks around the development of coping skills. Currently these other tasks are delivered by workers but in future versions more of these elements will be incorporated into the game. This game allows services to deliver interventions in a new way and allows services to reach those who can't or won't engage with traditional services.

The games is based on an existing activity within a structured day programme. A structured day programme aims to teach service users a series of skills for their recovery. This programme includes a variety of activities and sessions aiming to train users in a number of areas including motivation to overcome issues, coping skills and general life skills. It is highly structured with participants expected to attend for several hours daily. Each cohort of individuals on the course moves through the programme together. Half-way through the programme a session focuses on triggers and cravings and contains an activity about identification of potential triggers. This task involves the session facilitator setting up the room to contain multiple different triggers. The room is set up to contain an area that is set out like a domestic room with some drug cues (e.g. needles and foil) and a bar scene containing triggers related to the consumption of alcohol (e.g. pint glasses and beer cans). The facilitator gives each participant a set of colored stickers and sets them the task of exploring the "scenes" and tagging their triggers with the stickers. The group then gathers to discuss the session and talk about the triggers they have identified. This approach has several limitations:

- It requires equipment to be transferred to the service delivery location
- It requires time and space to set up
- It is limited in the type of triggers that can be displayed; the breadth of triggers is limited to simple physical objects and the task is unable to replicate interpersonal situations, outdoor scenes or other stimulus

The computerised approach to this content should offer the following advantages over the physical mock-up of the environment:

- a wider choice of the scenes that users can explore
- a higher number of triggers can be included
- the use of non-static triggers such as interpersonal situations

- easier monitoring and recording of users actions such as the triggers they tag and their movements
- less equipment required for the activity
- less preparation time needed to set up the activity
- potentially a more engaging experience for users
- more realism in the scenes presented

4.2 Early User Consultations

The project engaged with service users early in the development of the concept of the "spot the triggers challenge" virtual environment. Participants were recruited via their substance misuse workers. Researchers communicated the needs of the project to these workers and asked them to identify any individuals they worked with who would be suitable for involvement in the development process. The selection criteria were broad to allow input from as wide a range of service users as possible. Our requirements were:

- A history of substance misuse
- Willingness to engage in discussion and give feedback
- Engaged with treatment services
- Not presenting an undue risk to themselves or others

Additionally researchers requested additional focus on those in hard to reach groups such as young or female participants who traditionally do not engage with services in large numbers (statistics reveal that the average service user is 34 years old and 73% are male (NTA, 2011)). The needs of the project were communicated to staff through internal communication and briefings. We provided fliers and information sheets to assist workers in sparking interest in the project.

Through this we recruited 31 service users who were interviewed in either small groups or one-to-one interviews. This group tended towards an older male demographic. Whilst this matches the profile of drug and alcohol service users it is less ideal for reflecting the make-up of the substance misusing population as a whole, particularly as we wanted to encourage those who traditionally do not engage. Participants included 22 alcohol service users and 9 drug service users who tended to be at later and relatively stable stages of their treatment journey. 48% came from the Birmingham or Sandwell area (an urban city environment), 23% came from Coventry (a smaller city) and the others came from various towns around Warwickshire and Leicester (more rural, less densely populated areas). Six one-to-one interviews took place and the other service users were engaged in group settings with groups of between 2 and 7 participants.

Those engaged in this stage of the process were consulted on several areas. They were presented with the initial demo version of the application, a small demonstration scene consisting of a street with some drug related cues (phone boxes, needles and foil) and a bar room with some simple furniture such as a bar and chairs and tables and glasses and bottles associated with alcohol. The interaction in the scene was limited to navigation around the scene and there were no interactive characters or events. The system was demonstrated to participants by the researcher, and participants were then given an opportunity to use the system themselves. They were asked about the following points:

- Would they be happy using a computerised system?
- Would they be happy to discuss their triggers and work with them in a virtual environment?
- What barriers do they anticipate to the use of the system?
- What scenes and triggers should be included?
- What sort of visual appearance should the system have?

Notes were taken during these sessions and were examined for key themes.

Their reaction to the demonstration was generally positive in regard to its potential to allow better preparation and practicing of coping skills, although there were some reservations including:

- Adaptability to meet individual user's experiences with service users commenting that "different people have different experiences" and stating that that range of experience needs to be reflected in the end application but that too much content all at the same time could "overwhelm" the user
- The level of realism within the product was a contentious issue with some participants stating that they felt the application needed to be very realistic to engage users and others felt that it needed to be limited in its realism in order to reduce the risks associated with craving causing relapse

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- The level of challenge in making the application widely available because of the need for equipment and staff involvement was also identified.

The most commonly identified areas for future developments were the addition of animated characters and greater levels of interactivity to encourage more immersion and engagement for the user.

The service users were also asked to think of triggers that should be included in the application. Their responses are summarised in table 1, with attention paid to the substance of choice of those informing us of the trigger.

Table 1. *Identified triggers.*

Trigger	**Those affected**
Drug paraphernalia (e.g. foil and syringes)	Drugs
Being in an area with available alcohol. Examples included bars and also places that were less easily avoided such as the local shop or supermarkets	Alcohol
Empty cans/bottles	Alcohol
Phone boxes (used for calling dealers; this tended to be more prevalent in urban areas and amongst older service users)	Drugs
Old friends (either those you used to use/drink with or those who don't know the issues you've had)	Both
Arguments with partners/families	Both
Bills (and associated stress)	Both
Money (both its availability and the stress arising from the lack of it)	Both
Beer gardens	Alcohol
Social occasions (particularly weddings and birthdays)	Alcohol
Other drinkers/drug users	Both
Off licenses/corner shops	Alcohol
Park areas (tended to be primarily associated with alcohol, particularly street drinking, but was also mentioned by drug users. Some local variation included canal areas being mentioned by service users in areas with large canal networks where the canal area frequently takes the place of parks as an outdoor venue for substance use)	Both

4.3 Evaluation Prototype

On the basis of this input from the service user consultations, another version of the virtual "spot the triggers challenge" system was developed in Unity3D, a games development platform. The developed game allows participants to explore a variety of virtual scenes they might encounter in their daily lives that would bring them into contact with different triggers. It builds on ideas from the initial demonstration prototype and extends the range of virtual scenes that participants might encounter in their daily lives. Additionally interactions were added such as conversations with virtual characters. Each of these scenes contains various different triggers the user can interact with. The scenes represented in this version of the game were:

- a street scene (to represent triggers such as encountering old acquaintances, phone boxes, beer gardens and a local shop)
- a bar (that includes triggers related to alcohol and social situations), see Figure 1.
- a domestic scene (that represents the triggers related to financial stress, home environment and interpersonal arguments and stress), see Figure 2.

Figure 1. *Identifying triggers in a virtual bar.*

Figure 2. *Identifying triggers in a virtual living room.*

5. EVALUATION

In order to assess the safety and effectiveness of the application, we are conducting an experiment in the secure and easily monitored environment of a structured group setting. This section describes the experimental design, and reports on one session with service users.

5.1 Experimental Design

Participants for this study were recruited from within an existing a structured day programme. Each cohort typically has between 4 and 12 people and will be assigned to either a control group or an experimental group on an alternating basis. Participants in the structured day care programme have already undergone a risk assessment prior to joining the programme and as such should not have risks of harm to themselves or others and are able to give informed consent.

The session of interest within the structured day programme deals with support networks, triggers and craving and the coping skills that can be used to overcome these trigger situations and the craving they incite. The session first involves a discussion around the kinds of support (both formal and informal) that people can access and the participants create a map of their support network. The next section deals with identifying triggers and will follow the procedure laid out for the traditional real-world task (control group) or the virtual reality task (experimental group). After this the facilitator discusses types of coping strategy with the group and helps them create action plans that they can put into place for the trigger situations they have identified as most relevant to them.

The control group performs the existing real-world activity as described earlier in the paper. The experimental group uses the virtual version of the task. Within the virtual version of the activity, one participant takes control of navigation around the scene and the tagging of objects identified as triggers. The other participants are able to observe their progress via a projector and are encouraged to discuss the process,

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debate the relevance of certain triggers and guide the actions of the participant using the system. Both groups will be assessed using the same outcome measures and user feedback questionnaires. The questionnaires will be completed by participants before and after the activity and will assess their levels of understanding and confidence in the activity's learning outcomes (their understanding of triggers and their ability to identify their personal trigger), their levels of engagement with the task and emotional responses to the task (e.g. any feelings of stress or craving they felt during the task). These questionnaires will be analysed to find the average feedback scores and the variability in response for both the virtual environment task and the traditional discussion based task. Any verbal feedback given is recorded for later analysis.

5.2 Initial Results

The first trial group was assigned to the experimental condition and attended by 6 service users who all took part in the session and completed feedback forms for the session. The participants were predominantly male (5 male, 1 female). All participants were actively engaged in the programme alongside regular one to one sessions with substance misuse workers.

The feedback from the group (both within the session and via feedback forms distributed at the end of the session) was mixed with one very vocally against the use of technology, feeling the delivery needed to be pacier and "realer" with a greater level of non-visual feedback such as sound and, ideally, additional mediums such as smell.

The results from the feedback forms indicated that most individuals understood and followed the activity. The majority also thought the activity generated discussion in the group with 4 out of 6 either agreeing or strongly agreeing with the statement "the activity stimulated discussion within the group". This is reflected in participation within the group which included all members discussing the issues.

Participants were asked to rate their level of understanding of triggers and their ability to identify triggers before and after the activity, on a scale of 'No confidence', 'some confidence', 'a lot of confidence' or 'complete confidence'. Before the activity, the service users tended to have a reasonable level of confidence in these areas, with 3 of the 6 participants reporting 'a lot of confidence' in their understanding of triggers and ability to identify their personal triggers. This is in line with comments from the group facilitator indicating they felt triggers should be covered earlier in the programme as they come up in other discussions with service users prior to the relatively late point in the programme in which they are formally covered. Comparing the users' ratings after the activity, three of the six service users did not report any improvements in either of the learning outcomes. Two participants indicated improvement in both outcomes (confidence increased by 2 points for both people, understanding increased by 1 point for one and 2 for the other). One service user reported a decrease of one point for both learning out comes.

The reported immersion was low with only one participant not completely disagreeing with the statement "I felt like I was in a real place". This affected the craving felt by the group with half the group completely disagreeing with the statement "I felt craving whilst using the system", one individual saying they neither agreed or disagreed with the statement and the others stating a slight disagreement. This was reflected in comments recorded about the purely visual nature of the system and the need for higher levels of feedback to other senses such as sound and smell.

Levels of engagement with the activity were varied. This was reflected both in the question responses relating to "feelings of engagement" with the section and through many participants' reluctance to take control of the game in the session (after the initial volunteers no one came forward to take control).

The session itself proceeded largely according to plan but was hindered by unexpected changes to the delivery space's layout resulting in the projection of images being more difficult and badly positioned limiting their effective use as a focus for the group. This detracted from the activity and user engagement in it.

Trials are currently ongoing and include plans for control groups which will enable us to compare the outcomes of the virtual and real world versions and assess the effectiveness of the computerised approach compared to the traditional version.

5.3. Deployment Considerations

The lessons learnt from this research so far about the practical delivery of this form of interactive tool include:

- *Be prepared to adapt to your delivery space:* Services are delivered in a variety of locations, normally decided not only on appropriateness but also on factors such as cost, location and availability. This

means that you need to be adaptable to different locations and ways of working and delivering. This is reflected in difficulties we had in delivering in the space provided in our initial trial

- *Not all demographics are comfortable with technology*: Services represent a broad range of demographics and as such will include people who are not very comfortable using technology. To facilitate this, the process should be as user friendly, error free and integrated into services as possible. This can be seen in the reliance of participants on facilitator guidance when using the application. Younger people tended to have a go and only ask questions when they had a problem with the interface whereas older individuals tended to need guidance on the basics of navigation through a 3D environment.
- *Different people respond to different things:* No learning style or approach applies to every individual; people tend to learn and engage in different ways and they also tend to be at different points of learning for specific subjects. This is reflected in our results that show some individuals responding to the activity and some not responding to it. This could indicate this form of activity would be better used in more selective cases, or through a process of self-selection.
- *There is a need for a wide range of triggers and situations:* The range of objects, situations and events that can act as triggers is large and can vary according to the age, background, and substance of choice and geographical location of an individual. This makes it challenging to create a programme that is universal whilst still having an individual impact. This is demonstrated by the large number of triggers identified in our consultations.
- *It can be difficult engaging end users to develop content and designs:* This problem is particularly acute in reference to hard to reach group as they tend to not be engaged with services and, by definition, those that are available for feedback are engaged and therefore presumably display some different characteristics from those who do not engage. This increases the risk in developing content and approaches as there is less certainty in the appropriateness of what you develop. This is demonstrated by the project's difficulty in finding a service user involvement group that represents a wide range of individuals

The initial results of our first trial group, whilst not universally positive, do offer a starting point for further development, giving us insight into needed improvements and shedding light on the potential best audiences for this technology. The literature indicates there is potential within both game based learning and the wider field of interactive technology to assist people in achieving behavior change especially in view of the unmet need in the provision of support.

Moving forward the project will require more extensive trials in both the current structured day settings and also wider ranges of settings and within hard to reach groups. Finally there also need to be assessment and implementation of the ways that this can be brought to a wider audience.

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Virtual reality exposure therapy for post-traumatic stress disorder patients controlled by a fuzzy logic system

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ABSTRACT

This paper describes the main characteristics of two integrated systems that explore Virtual Reality technology and Fuzzy Logic to support and to control the assessment of people with Post-Traumatic Stress Disorder during the Virtual Reality Exposure Therapy. The integration of different technologies, the development methodology and the test procedures are described throughout the paper.

1. INTRODUCTION

Nowadays, the increasing production exploring the Virtual Reality technologies is undeniable, particularly in the area of Medical Science. Although the three-dimensional (3-D) virtual environments have being frequently used in the neuropsychological area, the use of intelligent strategies for monitoring the patients' activities is rare. In general, the three-dimensional (3D) environments open new possibilities to create environments suitable for simulations in the rehabilitation processes of cognitive functions loss caused by traumas and injuries. These environments allow the simulation of real situations integrated with psychological evaluations, proposing tasks "with low risks to the patient". These characteristics stimulate the growing interest in the Virtual Reality Exposure Therapy (VRET) applications.

Many people suffer different traumatic events, but only 10% to 60% of men and 50% of women develop lifelong Posttraumatic Stress Disorder (PTSD) (Masci, 2001). PTSD involves a constant sense of fear generated by the improper consolidation of trauma in the autobiographical memory (Brewin, 1996). Foa and Kozak (Foa, 1986) argued that some exposure strategies to feared situations is common in many psychotherapies for anxiety and that confrontation is an effective treatment for the anxiety disorder. However, for some patients it is difficult to immerse themselves in a scene due to avoidance traumatic symptoms. Thus, the use of new technologies could facilitate the treatment of these patients. In this sense, virtual reality has been used as a tool for exposure and it has achieved positive results in the treatment of several anxiety disorders, including Specific Phobias, Social Phobia, Panic Disorder and PTSD (Meyerbröker, 2010).

This paper presents two integrated environments for PTSD treatment: the ARVET (Virtual Environment Exposure to Trauma), a 3-D virtual environment to stimulate the memory of the patient with PTSD and the SAPTEPT (Evaluation System to Patients with Posttraumatic Stress Disorder), which explores the Fuzzy Logic to support the patients evaluation submitted to the ARVET. The ARVET presents some scenes that incorporate stimulus to the emotional processing, allowing an increase or decrease of the emotional answer. The SAPTEPT combines the perceived anxiety, pointed by the patient, and the cardiac rate to classify the patient level of anxiety in mild, moderate or severe. The classification controls the stimulus provided by the ARVET environment.

This work is organized into 4 sections. Section 2 describes the main concepts related to the proposed systems; section 3 details the environment and presents the expected interaction results between the systems. Section 4 concludes the work and presents future research directions.

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2. GENERAL CONCEPTS

2.1 PTSD Treatment

PSTD involves a constant sense of fear generated by the improper consolidation of autobiographical memory of the trauma (Brewin, 1996). People with PTSD can not adapt back to their usual life. Thus, a re-reading of the environment they live will be fundamental to resize the experienced situations.

In recent years, different theoretical and practical approaches have been explored to assess and rehabilitate cognitive processes, such as visual perception, attention and memory, as well as training the motor skills (Ready, 2006). The Cognitive-Behavioral Therapy (CBT) is considered a good option for Post-traumatic Stress Disorder (PTSD) treatment. In general, it is performed by exploring techniques that include Psycho Education, Cognitive Restructuring Techniques, Anxiety Management, Imaginary Exposure and Live Exposure. Its aim is to break the cycle of symptoms leading to a habituation of stimuli. Moreover, it attempts to develop relaxation skills, enabling the patients' control of their emotional and physiological response in order to decrease their reaction when faced with stressful situations.

2.2 Virtual Reality

The Virtual Reality technology has been widely used in the cognitive stimulation, providing opportunities to offer some situations closer to the real world. Burdea and Coiffet (Burdea, 2003) defines the applications of Virtual Reality as a three-dimensional virtual environments that presents real-time graphics rendered by a computer, in which the user, via body position sensors or user-input devices, controls the viewpoint or the orientation of displayed objects.

In the last years virtual reality exposure therapy (VRET) has become a viable alternative for exposure in vivo, the gold standard for the treatment of anxiety disorders (Meyerbröker, 2010). In spite of exposure therapy, some patients find it difficult to imagine themselves in the scene due to avoidance symptoms, leading some of them to abandon treatment. In some studies, dropouts and non-response rates can reach 50% of cases (Schottenbauer, 2008). Therefore, the use of new technologies could smooth the progress of exposure to avoidant patients. In this sense, virtual reality has been used as a tool for exposure and it has achieved positive results for treatment of several anxiety disorders, including Specific Phobias, Social Phobia, Panic Disorder and PTSD (Meyerbröker, 2010).

The Virtual Reality Exposure Therapy (VRET) facilitates the emotional engagement of patients with PTSD during exhibitions, outlining the avoidance symptoms, and therefore facilitates the therapist control (Ready, 2006). According to Rothbaum and Mellman (Rothbaum, 2001), the sense of presence induced by the virtual environment, which is rich in sensory stimuli, helps processing the emotional memories related to trauma. This technological device allows gradual exposure to the feared environment, according to patient needs. In this sense, some experiments have been done worldwide. Torres and Nunes (Torres, 2011) used three-dimensional virtual environments with characteristics of "Serious Games" to simulate situations aimed at training and therapy. These games allow the simulation of real-world situations, providing training activities that stimulate cognitive functions and psychomotor skills. The study conducted by McLay et al. (McLay, 2011) evaluates the effectiveness of the VRET in the treatment of PTSD patients on the spot to combat in Iraq. According to these authors, three-dimensional virtual environments can be used to simulate situations aimed at training and therapy. In general, there is no automated control that gives the therapist results from the integration of different biofeedback variables obtained during the VRET. As an alternative, the inclusion of intelligent techniques, as Fuzzy Logic, can help to alleviate this problem by reducing the need of therapist decisions.

2.3 Fuzzy Logic

According to Zadeh (Zadeh, 2009) Fuzzy logic adds to bivalent logic an important capability—a capability to reason precisely with imperfect information. Imperfect information is information which in one or more dimension is imprecise, uncertain, incomplete, unreliable, vague or partially true. Fuzzy Logic uses the formal principles of approximate reasoning and searching to model imprecise modes of reasoning that are usual in the human decisions. It has been a powerful tool, which is able to capture inaccurate information described in natural language and translate them to a qualitative and quantitative form, allowing the position of super categories.

Traditionally, a logical position has two extremes: "true" or "false". However, in fuzzy logic, a premise varies in degree of truth or relevance falling in the range 0-1, which leads to concepts of partly true or partly false. The control performed by the fuzzy logic mimics behavior-based rules, rather than a control explicitly restricted to deterministic models. The goal of Fuzzy Logic is to generate a logic output from a set of non-

precise inputs, noisy, incomplete or even absent ones. According to Braga et al. (Braga, 1995), “Fuzzy Math is an attempt to bring together the characteristic precision of mathematics and the inherent imprecision of the real world, born from the deep desire to better understand the mental processes of reasoning”.

Fuzzy Logic has been successfully exploited as a tool to support the analysis of tests of three-dimensional environments (3D), devoted to the teaching and training of medical practices (Santos, 2011).

3. THE ARVET AND SAPTEPT SYSTEMS

Usually, the treatment of a patient with PTSD, provided by the Stress Research Laboratory (Laboratório de Pesquisa Integrada do Estresse LINPES-UFRJ) explores two stimulation strategies: imaginary and live. In imaginary exposure, the patient informs the details of the trauma in a sequential manner at each visit. In this case, the patient is exposed to the reported trauma listening to an audio recorder. In the live exposure the intention is a direct and graduated confrontation to the feared objects or situations.

To support the LINPES practices we develop two applications to help both therapists and patients, in the live exposure process. First, it is built a hierarchy of feared situations to construct a collection of virtual environments to support the exposure to different levels of intensity: the ARVET - Environment Virtual Reality Exposure to Trauma. The ARVET is a collection of virtual reality environments that were built with the possibility of stereoscopic viewing through a large screen and the use of appropriated glasses, which interacts with the patient and stimulates them. The tools used to create this environment were: Blender 2.5 to model objects in the scene and Unity3D 3.4.2 for the animations and interactions. The first prototype simulates some situations involving in urban violence. Figures 1 and 2 show some images of ARVET.

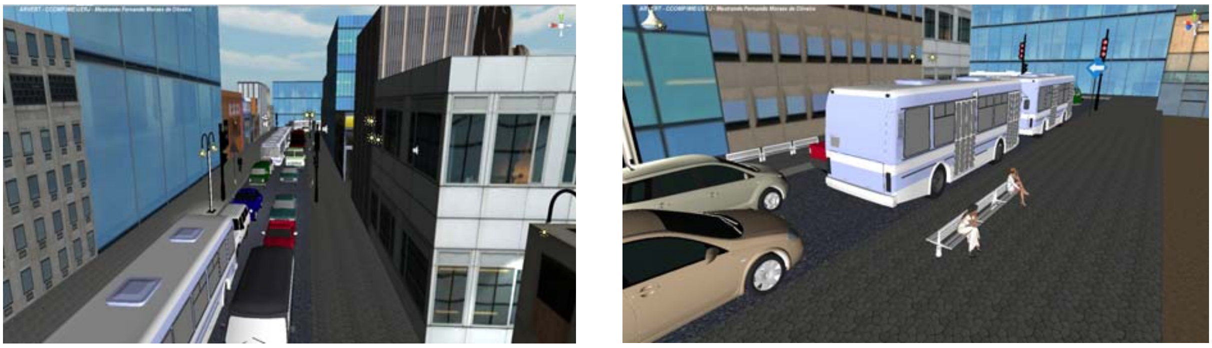

Figure 1: *The ARVET environment: general views*

Figure 2: *The scene of an accident: a person was hit by a bus.*

The exposure to virtual environments can generate reactions and perceptions, which are difficult to be assessed jointly by the therapist. Aiming to integrate these data and classify the patient in real time during the VRET process, we developed an application that explores the techniques of fuzzy logic - the SAPTEPT - System of the Evaluation of the Patients with Posttraumatic Stress Disorder.

The LINPES researchers distinguish the groups of Psychometric and psycho-physiological variables, whose values are collected during evaluations. Psychometric scales are established by filling in forms of self-report and Psycho-physiological data are obtained through the Biopac (Physiological various data acquisition system).

The option to have the patient level of anxiety is the SUDS scale - Subjective Units of Disturbance Scale to assess the degree of anxiety during the trauma stimulation. The SUDS is a range of integer values between 0 and 10 that measures the intensity of disturbance or distress experienced by an individual when subjected to trauma. For example, the individual answers to the value of this scale that refers to the level of anxiety at the time of exposure to the trauma, ranging from “no anxiety” to “high anxiety”.

A meta-analysis conducted by Pole (Pole, 2007) identified the Heart Rate as a Psycho-physiological group variable that changes when PTSD patients are exposed to a traumatic stimulus. Thus, the heart rate level confirms or not, the patient’s anxiety. In this case, we consider the level of anxiety reported by the patient and the heart rate. Table 1 presents these variables.

Table 1. *Variables involved in the SAPTEPT system.*

Psychometric Scales	Psycho-physiological Variables
Anxiety	Heart Rate

The Fuzzy Logic used in SAPTEPT captures inaccurate information, described them in natural language and converts them in qualitative information. The Fuzzy Logic can control the behavior of a system by changing the inputs according to a set of inference rules. These behavior-based rules model the system operations. The method, from the viewpoint of fuzzy logic, allows us to recognize patterns of anxiety gradual scale (Mild, Moderate, and Severe) in real-time measurements, when the psychometric scales (anxiety) and psycho-physiological (heart rate) are performed (Figure 3). Pattern recognition is one of the oldest and most obvious applications in the area of Fuzzy Theory.

This system classifies the patient’s degree of anxiety while they are navigating in the ARVET, then it indicates the change to be done in the virtual ARVET scenario. All tasks, scenes and the patient classification in the Fuzzy System were proposed by a group of psychologists, which are responsible to test these systems with their patients.

		HEART RATE		
		Mild	Moderate	Severe
ANXIETY	Mild	MILD	MODERATE	SEVERE
	Moderate	MODERATE	MODERATE	SEVERE
	Severe	MILD	SEVERE	SEVERE

Figure 3. *Fuzzy inference table.*

The SAPTEPT was developed in Python programming language and shows the classification of the patient every five minutes from the start of the evaluation, monitored by a therapist, to the end, along with their degree of relevance is obtained by Fuzzy Sets.

After the patient is classified in a new level, the therapist will ask him to open a door and enter in an environment, changing the stimulus level of the scenes (Figure 4). A pipeline of the system use is presented in Figure 5.

3.1 Perspectives

Aiming at analyzing some aspects of the prototype, we developed an evaluation experiment with two psychologists. This evaluation considered some usability aspects as: navigation facility; learning facility; response time; realism of scenes; pleasantness of the scenes; adequacy of objects in the tasks and matching colors.

The initial results of this experiment indicated that the 3-D environment has a high level of usability, but some aspects must be changed: some colors, some architectural details and the speed of buses and cars. At the other side, the Fuzzy system must have its interface slightly modified in order to facilitate responses from users about their anxiety level.

Figure 4. *The doors where the patient must enter to change the level of stimulation.*

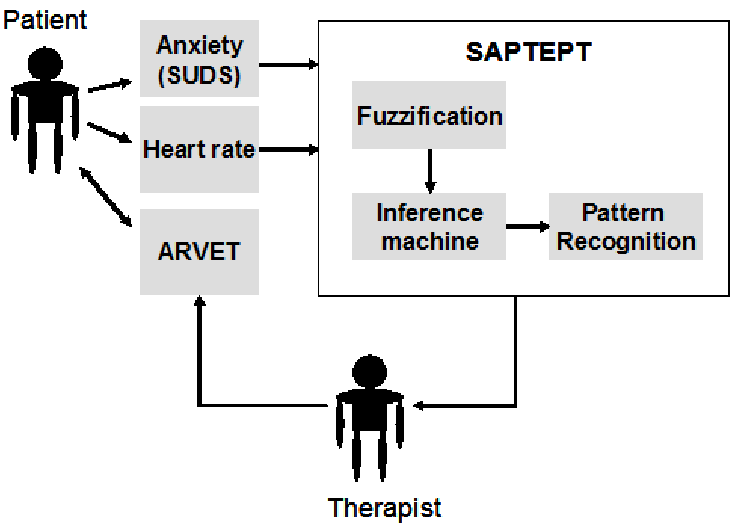

Figure 5. *The pipeline of system utilization.*

After those steps, the system will be used by a group of people with Posttraumatic Stress Disorder to measure its efficacy in control the level of tasks according to the patient evolution. The prototype can be used in the first instance for cases of patients diagnosed with PTSD due to hits or car accidents (very common in large urban centers).

4. CONCLUSIONS

In Brazil, there is a growing interest in the Virtual Reality technology to support health care procedures. In this sense, we need new software and new treatment strategies, where patients may have more unrestricted access to the exercises and the therapist can monitor the result in a precise way. Thus, in this case, the virtual environment must have some mechanisms to control user navigation and generate automatic reports to the therapist.

However, the development of such software depends on the integration of different technologies and expertise. The Fuzzy Logic offer large possibilities to control the user answers and support the therapist decision-maker.

This paper presented some results of a project that has two objectives. The first one is associated with the technical questions related to the intelligent strategies related to decision supporting and how to integrate this with specific virtual three-dimensional environments.

Some therapists (psychologists) tested the system and proposed some changes that were considered in a new version of the system. Now, the system is being tested with a group of people with PSTD associated to car accident and car hits.

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Virtual exercises to promote cognitive recovery in stroke patients: the comparison between head mounted displays versus screen exposure methods

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ABSTRACT

Stroke can be considered as a major cause of death and the consequences are associated with different syndromes of the impaired physical, cognitive, behavioral and emotional domains. The cognitive rehabilitation is often related to improvement on executive functioning through repeated and systematic training in memory and attention exercises, in which virtual reality has proven to be a valid approach. Several devices have been used as visual outputs. Head mounted displays (HMD) and desktop screens displays are amongst them. HMD is usually perceived has being more immersive than screens. However, it presents several shortcomings if a widespread use is the objective. In this way, this study aims at assessing the prospect of opting for screen displays as an alternative to HMD within virtual reality (VR) based applications to rehabilitate memory and attention impairments in stroke patients. A sample of 17 patients with memory and attention deficits resulting from stroke were recruited from the hospital *Centro de Medicina da Reabilitação do Alcoitão*. The patients were randomly assigned to two different groups: (1) HMD based VR; and (2) desktop screen based VR. The patients in the experimental groups underwent a virtual reality (VR) training programme with 12 sessions regarding memory and attention exercises. These patients were assessed before and after the VR training sessionswith the Wechsler Memory Scale for memory and the Toulouse Pieron for attention functioning. The results showed increased working memory and sustained attention from initial to final assessment regardless of the VR device used. These data may suggest better functional independence following VR-based intervention and support the use of non-expensive displays as an alternative to high-end setups commonly used in VR applications devised for rehabilitation purposes.

1. INTRODUCTION

Stroke is a major cause of death in the developed countries and can give way to severe cerebral lesions that are accountable for motor disabilities and cognitive impairments, resulting in personal, professional and social dysfunctioning (Wang et al, 2004), . Most of the impairments reveal themselves in the form of attention and memory deficits that, more often than not, may compromise patients' daily life activities. Being so, a recurrent approach devised to rehabilitate these functions should rely on exercising daily life activities through systematic and regular training (Baümer et al, 2001).

In this context, several studies are in development in order to assess the role of neuropsychological rehabilitation in cognitive and motor recovery. The scientific literature is in agreement with respect to the development of neuropsychological approaches, that they have to gather the scientific knowledge from different areas of psychology. The most widely known approaches for cognitive rehabilitation are function based approaches for neuro-rehabilitation since this are focused on a specific cognitive or motor domain

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(Sohlberg and Mateer, 2001). The repetitive practice is also an important aspect in motor and cognitive training as it improves performance in disabled patients (Chen et al, 2004).

The exercises devised to rehabilitate motor disabilities or cognitive impairments should observe rehabilitation's trinity: repetition, feedback and motivation (Holden, 2005; Allred et al, 2005; Cirstea and Levin, 2007). As an attempt to boost these entities, virtual reality (VR) exercises are now considered a sound option. VR offers the possibility of an endless repetition, providing visual, auditory and haptic feedback; and, because VR platforms are usually perceived as a game, patients are engaged, driven and, as a result, motivated by the exercise (Allred et al, 2005). In fact, according to Cirstea and Levin (2007) in a virtual environment, training exercises can be considered as more engaging and motivating than the traditional approach.

Also, some authors (Levin et al, 2005) argued that using VR applications in rehabilitation may benefit training purposes, mainly through the 3D spatial correspondence between movements in the real world and movements in the virtual worlds, which may facilitate real-time performance feedback. While repeating the exercises, patients' senses are provided with feedback about the accomplishments achieved, which may improve performance in disabled patients.

VR seems, during hospitalization, to promote a more intensive and program supportive approach to the execution of exercise, providing appropriate feedback to the patient. Also, exercises may be displayed with an adapting degree of difficulty, making possible the use of non-invasive forms of physiological monitoring. VR, in addition, gives therapist the ability to individualize treatment needs, while providing the opportunity for repeated learning trials and offer the capacity to gradually increase the complexity tasks while decreasing therapist support and feedback (Weiss and Katz, 2004). VR is a promising response to shorter hospitalization and foster homecare (Giorgino et al, 2008).

Motor aspects of using VR environments were also studied (Viau et al, 2004). They analyzed movements performed by participants with hemiparesis with virtual objects in VR and real objects in real environments. These authors found no differences between the movements performed in VR and real environments and suggested that this VR technique can be an effective training for rehabilitation. Other studies (Edmans et al, 2006) aimed at training a specific function (making a hot drink) in stroke patients in a real and virtual world conditions. Data suggested that virtual applications can be used for rehabilitation of stroke, but the neural mechanisms underlying performance in a virtual world can be different than real life situations. For example, real world performance was associated only with motor planning, whereas in a virtual world performance was more associated with praxis. Moreover, Knaut and collaborators (2009) studied arm and trunk movements with kinematics in a sample of stroke patients with hemiparesis. Results were in line with previous studies and can suggest that VR can be used for clinical interventions with these patients.

Typically VR may be experienced using one of following types of settings: (a) desktop personnel computer (PC); (b) workbench; (c) CAVE (CAVE Automatic Virtual Environment), (d) HMD (Head Mounted Display) and (e) screens. PC, workbench and CAVE are usually neglected on rehab studies. On the workbench, immersion and presence levels are reduced and the CAVE represents a financial investment difficult to attain by the majority of the research groups. Consequently, HMD and screens are the most currently used. The HMD, when associated to a tracking system, allows a 360 degree field of view and 3D stereoscopy, which is considered to be responsible for its effectiveness on immersion. On the other hand, most HMD are heavy, expensive and, when used for long time, may cause retinal strain. Screens allow more than one subject at a time and are not as much intrusive as HMD are. Nevertheless, and because field of view is limited to projection area and as tracking system is missing, screens are usually considered to be less immersives.

Although the use of VR devised to rehabilitate motor and cognitive impairments is being studied intensively, there is no agreement regarding the best way to provide VR exercises to brain lesion patients. Given the previous literature on this topic, the main purpose of this study was to test the use of a VR training environment to promote cognitive recovery of memory and attention deficits in stroke patients, but also to compare memory and attention outcomes between two groups of stroke patients using, each, HMD or PC screen displays.

2. METHODOLOGY

2.1 Sample

A sample, consisted of 17 patients (M= 51 years old; SD = 14 years) , in which 58% were males and 42% were females with memory and attention deficits as a consequence of stroke was collected from the

rehabilitation hospital *Centro de Medicina da Reabilitação do Alcoitão*. All patients had more than 12 years of formal education.

Exclusion criteria were as follows:

- More than 6 months after stroke episode (Figure 1);
- Comorbidity of language disorders;
- Dementia;
- Other previous psychiatric disorders that may have an impact on memory and attention, such as drug addiction behaviors or severe depression.

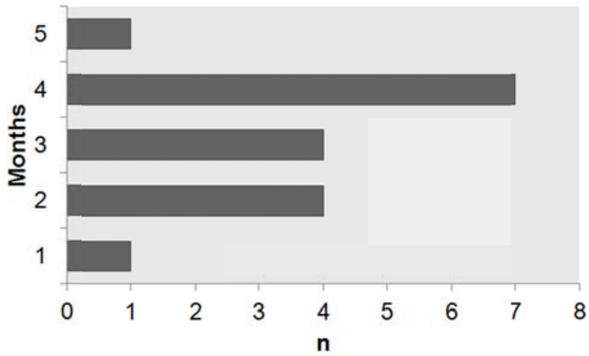

Figure 1. *Time since injury.*

From the initial sample, 9 patients (M = 55 years; SD = 9 years) were assigned to the desktop VR experimental group, whereas the remaining 8 patients (M = 45 years; SD = 16 years) to the HMD experimental group.

There were no significant differences in age and years of education and time since injury between the patients assigned to desktop VR and HMD ($p > 0.05$). Moreover, gender was also equally distributed between the two experimental groups ($p > 0.05$).

2.2 Measures

Given that cognitive impairment after a stroke is frequently associated memory and attention impairments, each patient was assessed through a brief screening test, the Mini Mental Examination Test (Folstein et al, 1975) that was previously validated to the Portuguese population by Guerreiro and collaborators (1994) . Memory and attention deficits were considered when Z scores in memory and attention subscales were 2 SD (standard deviation) bellow the normative data.

During the neuropsychological intervention, our main concern was to stimulate memory and attention abilities since these are important components of executive functioning. In this way, each patient was assessed in two different moments (before and after training) with the Wechsler Memory Scale – WMS-III (Wechsler, 1954) and the copy of Rey Complex Figure – RCF (Osterrieth, 1994) for neuropsychological evaluation of memory, and the Toulouse Piéron – TP (Piéron, 1955) for attention and concentration abilities.

2.3 Procedures

This study was carried out at the Psychology Department of the *Centro de Medicina de Reabilitação de Alcoitão*, Lisbon, Portugal.

This study leaned on different types of cognitive exercises that were performed by 9 patients in a HP Intel® Core™2 Quad Processor Q6600 PC equipped with a GeForce GT 220 and a 21’’ Asus VE228D screen display (1680 X 1050 pixels of screen resolution); and by 8 patients in the same PC but, in this case, plugged to a HiRES eMagin Z800 HMD.

The VR environment was developed using Unity 2.5 (Unity TechnologiesTM) and consisted of a small town with a 2 room apartment and a minimarket in the vicinity. The interaction with the VR environment was performed using left mouse button to move forward and the right to move backwards. The space key on the keyboard was configured as an action button, to grab the objects and interact with virtual objects. Patient’s avatar was spawned in the apartment’s bedroom, from where they accomplished each session tasks by moving towards the final goal described bellow. The therapist role was to explain sessions’ procedures and to assess the session outcome.

The study design unfolded throughout 12 sessions (one session per week). On first session, memory and attention tests (WMS-III, RCF and TP) were applied. On second and third session patients acquired computer interaction skills on a training platform. The next nine sittings were used for cognitive training by VR.

Cognitive training comprised personal orientation tasks, such as the execution of daily living activities of morning hygiene, meal preparation and dressing (i.e., choosing the right clothes to wear); working memory (i.e., buying several items with a certain amount of money) and recognition memory tasks (i.e., recognition of outdoor advertisements); visuospatial orientation tasks (i.e., finding a different way to the minimarket) and selective attention tasks (i.e., finding a yellow dressed virtual character). In the last session were applied again memory and attention tests. An example of these tasks can be found bellow (Figure 2).

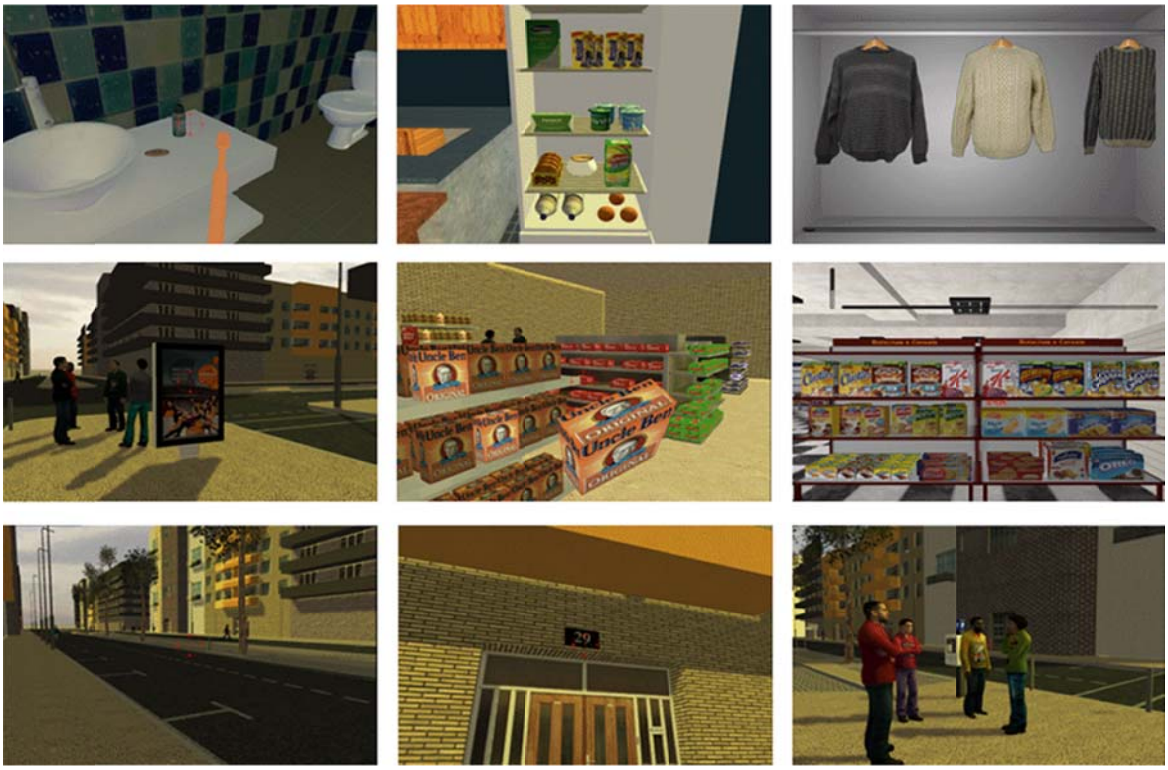

Figure 2. *Example of the VR training tasks. The top panel shows personal orientation tasks, the mid panel is for working memory, whereas visuospatial orientation and selective attention tasks are illustrated at the bottom panel.*

3. RESULTS

The statistical procedures were carried out through repeated measures ANOVA with one within-subjects factor (before intervention vs. after intervention) and a between-subjects factor (HMD vs. desktop screen).

As regards to memory, the ANOVA performed to WMS total scores and to RCF scores showed a main effect of evaluation in the WMS ($F(1, 16) = 12.491$; $MSE = 117.813$; $p < 0.01$) and the and the RCF ($F(1, 16) = 8.676$; $MSE = 19.709$; $p < 0.05$).

These data revealed a significant increase in WMS scores ($M = 85.71$; $SD = 3.89$ vs. $M = 98.94$; $SD = 3.99$) and RCF score ($M = 11.41$; $SD = 1.83$ vs. $M = 15.77$; $SD = 2.49$) from initial to final assessment. However, no significant interaction effects were reported between factors ($p > 0.05$) in the WMS and RCF assessments (Figure 3).

Also, data indicated a main effect of evaluation in the TP test ($F(1, 16) = 15.935$; $MSE = 542.598$; $p < 0.01$), suggesting that sustained attention increased from initial ($M = 75.69$; $SD = 10.83$) to final assessment ($M = 108.56$; $SD = 16.23$) when assessed with the TP test. There were no significant interaction effects ($p > 0.05$) between evaluation and VR device (Figure 4).

These data also suggest that the use of VR environments might be a valid alternative for cognitive training in stroke patients. A control sample is, however, missing. Enhanced working memory and attention

and concentration abilities may also imply better functional independence in brain injured patients, which is one of the major goals of neuropsychological rehabilitation.

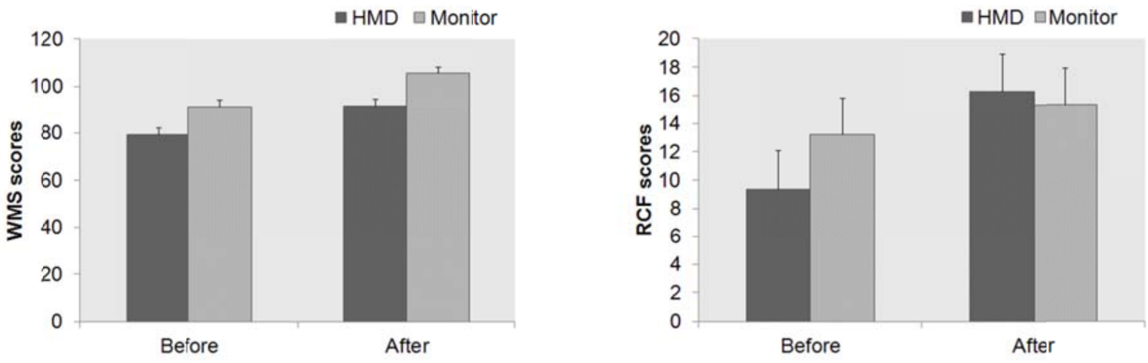

Figure 3. *WMS mean scores (left figure) and RCF mean scores (right figure) to each experimental condition.*

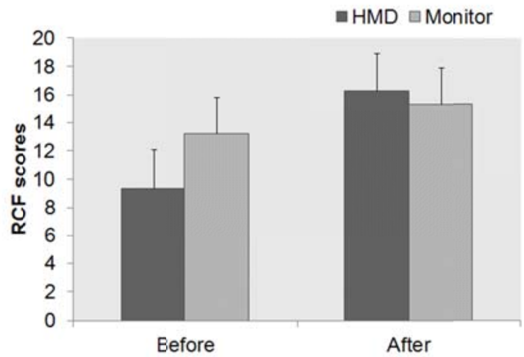

Figure 4. *TP mean scores to each experimental condition.*

On the other hand, results revealed no interaction effects between factors ($p > 0.05$), suggesting that these improvements did not interact with display method of exposure. These outcomes may indicate that training cognitive functions in VR settings is, probably, an option to traditional training procedures and that non-expensive displays, like PC screens, are an alternative to posh setups such as the HMD.

4. CONCLUSIONS

VR applications have long been applied for rehabilitation purposes. Its use to train cognitive functions it is now common. VR applications carry out several advantages when compared to the traditional counterparts. They are immersive, enable a certain amount of free will and they are ecological sounded. One entity that has been working as a propeller is the videogame industry. There are now available off-the-shelf graphic engines that are relatively easy to use and that produce realistic and interactive synthetic worlds. Also, on the hardware side, computer components like CPUs and graphic boards are giving a hand. So are the associated output devices such as screens, HMD (head mounted devices), or CAVE (Cave Automatic Virtual Environments).

Screens and HMDs are usually therapists' choice (CAVE are expensive and require extra manpower). HMD are immersive and, more often than not, are coupled with a head tracker that emulates one's head movement in the virtual world. On account of that they should be "today's special". However, they are not. They are more expensive than screens, they can cause visual discomfort and, above all, they are a stand-alone extra difficult to justify for lay users such are common patients and therapists. Furthermore, the evolution of screen based displays has placed screens competing shoulder to shoulder with HMD technology. The quality of both general purpose TVs and computer displays, allied to first-rate and rather cheap sound systems, enable a decent immersive experience that could only be obtained, a few years ago, by HMD.

This apparent similitude is, however, in need to be challenged by scientific data. Accordingly, this paper aimed at comparing two samples of stroke patients that had each trained memory and attention functions with

a HMD and a PC screen display. The results showed that the observed improvement on those functions was independent from the device that was in use. This may indicate that screen based displays are a sounded option to HMD.

As in western countries the elderly population is increasing and the average age of stroke is decreasing, combined with reduced hospitalization periods, the need for rehab applications that can be handled outside health institutions facilities is paramount. Without the direct support of well-trained caregivers, exercises should be devised to be as much straightforwardly as possible. And so is the gear used for the VR experience. Under the same circumstances, i.e. producing equivalent therapeutic outcomes, the choice should go towards cheaper and easy to handle device such are screens.

In addition, this study also points towards the prospect of using VR exercises aimed at training memory and attention functions in stroke patients.

The cognitive rehabilitation exercises used in our programme were developed according to a cognitive retraining rationale with focus on memory and attention functions (Sohlberg and Mateer, 2001). In agreement with these authors the repetitive training of specific cognitive skills can help to recover disrupted functions leading to better adjustment in personal and social domains.

Indeed, despite the aim of the each intervention programme, meaningful improvement in patient's everyday living activities must be the major goal of rehabilitation. One suggestion for further studies is that evaluation should focus also on the level of activity and engagement in activities of everyday living (ADLs). For example, level of performance in ADLs could be assessed through the caregivers' opinions that could allow the understanding of personal, professional and social adjustment of these patients in basic and instrumental ADLs.

Also, controlled trials should be carried out in further studies to enable the comparison of VR based interventions with other conventional approaches or even with a waiting list group.

Although there is lack of support regarding the effectiveness of VR-based applications in cognitive rehabilitation, motor aspects of using VR environments were studied (Viau et al, 2004; Edmans et al, 2006; Knaut et al, 2009). These studies have suggested that the 3D spatial correspondence between movements in the real world and movements in the virtual worlds can benefit training purposes with VR applications. Another important issue with rehabilitation is the patient's motivation to perform the predetermined exercises. In agreement to some authors training in a VR setup is perceived more as a game and less than a task and can be considered as more engaging and more stimulating than the conventional methods of rehabilitation.

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Design of virtual reality based physical and cognitive stimulation exercises for elderly people

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ABSTRACT

Elderly people are the most growing part of the population in developed countries (Europe, North America and Japan). This population is getting more and more alone and isolating this part of the population is the big issue of this century. This isolation can lead to a lack in physical and cognitive activity. Because virtual reality has given good results in health domain, we decided to design an application that combines physical activities and cognitive stimulation. The "Balade à l'EHPAD" application was then tested on different kind of population. Then, the expectations and needs of elderly people were collected and analyzed. The results clearly indicate that preconceived ideas exist in every people and also in professional caregivers who generally have a better knowledge of this population. Elderly people would like to have raw colors and virtually practice more violent sports (*e. g.*, skiing, rugby). The overall study clearly indicates that more than for younger adults, the involvement of elderly people into the application design process is a prerequisite for the appropriation by this population.

1. INTRODUCTION

In France, 8.5% of the general population are elderly people (aged 75 or more); they will be more than 30% in 2060 (Blanpain and Chardon, 2010). This assumption is also true in other European countries as demonstrated by (Adveev et al, 2011). Aging is often accompanied by decline of cognitive functions, especially in case of dementia and Alzheimer Disease (AD) (Ankri, 2009), and is correlated with an increase of loss of autonomy (Bonnet et al, 2011). Recent studies showed the beneficial impact of physical exercise for older adults (Chodzko-Zajko et al, 2009), and on cognitive functions among people with Mild Cognitive Impairment (MCI) (Geda et al, 2010), whose deficits may be a precursor for dementia. In this context, different types of nursing homes for elderly dependent people frequently ask for new methods including information and communication technology for cognitive and physical stimulation approaches.

During the last years, the use of Virtual Reality (VR) in health domain has given positive results (Rizzo and Kim, 2005; Klinger et al, 2010). In MCI or AD contexts, VR can help respectively to assess dysexecutive functioning (Werner et al, 2009), or to detect navigational deficits (Cushman et al, 2008). VR-enhanced exercises can combine motivating game-like activities within virtual worlds and physical training; they considerably enhance health outcomes (Lange et al, 2010). Cassilhas *et al* demonstrated that resistant exercise had a positive impact on cognitive function in elderly people (Cassilhas et al, 2007). A recent study among 102 older adults tested the benefit of VR-based simultaneous cognitive and physical exercise on cognitive decline (Anderson-Hanley et al, 2012). The results showed that "cybercycling" training during 3 months has greater potential for preventing cognitive decline than similar effort on a traditional stationary bike.

In this context we designed the "Balade à l'EHPAD" project in early 2011, a VR-based application in which elderly people are involved in a bike ride within different virtual environments. During the ride, they are invited to participate to several simple games to stimulate some cognitive abilities (Figure 1). This application was rapidly designed based on discussion and a quick collection of care givers needs. They strengthen the fact that elderly people located in specialized care houses do not have a lot of physical

activities. We rapidly imagined the possibility to design a VR based application which would be driven by a physical interaction between the human and the machine.

The aim of this paper is to present a usability study of the first version of the “Balade à l’EHPAD” application which focuses on usability issues, participant interactions and behaviors. The purpose of the study was also to build recommendations for improving this first version.

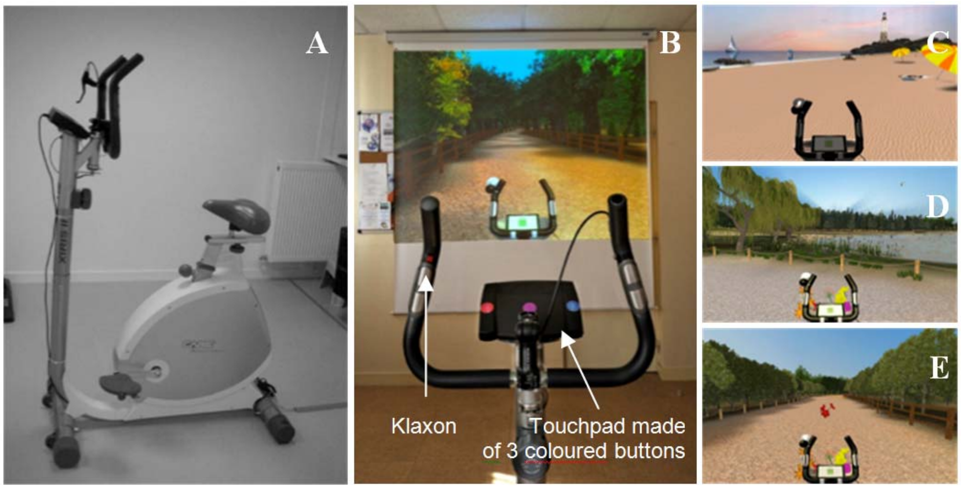

Figure 1. *“Balade à l’EHPAD” provides an interfaced bike (A) for a virtual bike ride (B) in two different environments: the seaside (C) and a forest (D). The participants are suggested to be involved in simple cognitive exercises as collecting flowers (E).*

2. MATERIALS AND METHODS

The evaluation of the “Balade à l’EHPAD” application was essentially carried out with usability testing (Hornbaek, 2006).

2.1 Instrumentation

The “Balade à l’EHPAD” application is made of two parts: the software part consists of a all-in-3D application build using Unity integrated development environment (Guiping et al, 2011); the hardware part is made of a beamer and a bike interfaced with the computer running the application (Figure 2).

Figure 2. *Instrumentation of the “Balade à l’EHPAD” application. The application is made of a bicycle simulator interfaced with the computer running the VR-based application. The environment is displayed by a beamer on a 78” screen.*

2.2 Settings and Participants

Participants were recruited in three different populations: professional care givers, healthy participants and elderly people. Professional care givers are people working in the institution where the elderly people live (“Centre Inter-Générationnel Multi-Accueil”, CIGMA, Laval; “Polyclinique de Laval”;”Foyer Thérèse

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Vohl", Laval). Healthy participants are safe subjects not directly related to the institution and elderly people are people living in one of the previously cited institutions. The panel contained 7 professional care givers (age between 20 and 36 Y.O.), 4 healthy participants (age between 22 and 52 Y.O.) and 15 elderly people (age between 82 and 97 Y.O.).

2.3 Evaluation Procedure

The "Balade à l'EHPAD" application invites participants to ride a bike simulator within virtual environments (VE) simulating natural spaces like a forest and the sea side (Figure 1 and Figure 2). The participant rides on a bike simulator with the illusion to move in the VE. In each virtual situation, simple cognitive exercises are suggested to the participant, like collecting flowers with specified colors (Figure 1E). A touchpad, fixed on the bike handlebar, allows the user to interact with the different items displayed in the VE by pushing three buttons with different colors: red, purple and blue.

Two different tests were carried out: a usability test with the "Balade à l'EHPAD" prototype followed by a questionnaire (test A) and a questionnaire without any usability test (test B). Test A was carried out among professional care givers and healthy participants. Because of the very preliminary version of the prototype and for safety issues of elderly people, this population sample carried out test B which does not include the bike ride.

Thus, test A questionnaire gathered information about 1) the adequacy between the prototype and the initial objectives; 2) the adequacy of the equipment and the expected audience; 3) the professional care givers needs and expectations, and 4) motivations and interests in the project. Finally, test B questionnaire was dedicated to collect needs, expectations, preferences and missing characteristics for elderly people.

2.4 Evaluation Criteria

An exhaustive list of the evaluated criteria was set in order to build the questionnaires. The retained criteria to evaluate the "Balade à l'EHPAD" application are listed in Table 1.

Table 1. *List of criteria used to evaluate "Balade à l'EHPAD" application in test A.*

Criterion category	Criterion
Content	Graphical User Interface (UI)
	Virtual environments
Computer graphics	Graphical coherence
	Virtual environment
	Fonts
	First person representation
	Sound
	UI visibility
Ease	For professional care givers
	For participants
Flexibility	Software
	Hardware
Interaction	Interaction artifacts
	Navigation artifacts
	Goal
	User control
Hardware	Bike
	Touchpad
	Horn
	Screen
	Health impacts
UX and satisfaction	Virtual User eXperience (UX)
	Satisfaction
Utility	Utility
Accessibility	Accessibility
Software performance	Performance

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3. RESULTS

3.1 Usability Testing

The results of the usability test as provided by the test A are shown on Figure 3. The left part of the presented results (on a blue background) is related to the adequacy between the impressions of participants and care givers and the objectives of the initial project. The following questions were answered:

- Adequacy with initial objectives
  - Does the application respond to the objective of allowing people physical activities?
  - Does the application respond to the objective of well-being for people riding?
  - Does the application respond to the objective of cognitive stimulation of people?
- Hardware
  - Is the bike appropriate for the objectives of the application?
  - Is the 3 buttons touchpad appropriate for answering questions?
- Cognitive stimulation exercises
  - Would it be useful to include usability familiarization activities?
  - Would you like to have different levels in the proposed cognitive activities?

The answers to these “test A” questionnaires are presented as a number of occurrences of each given term.

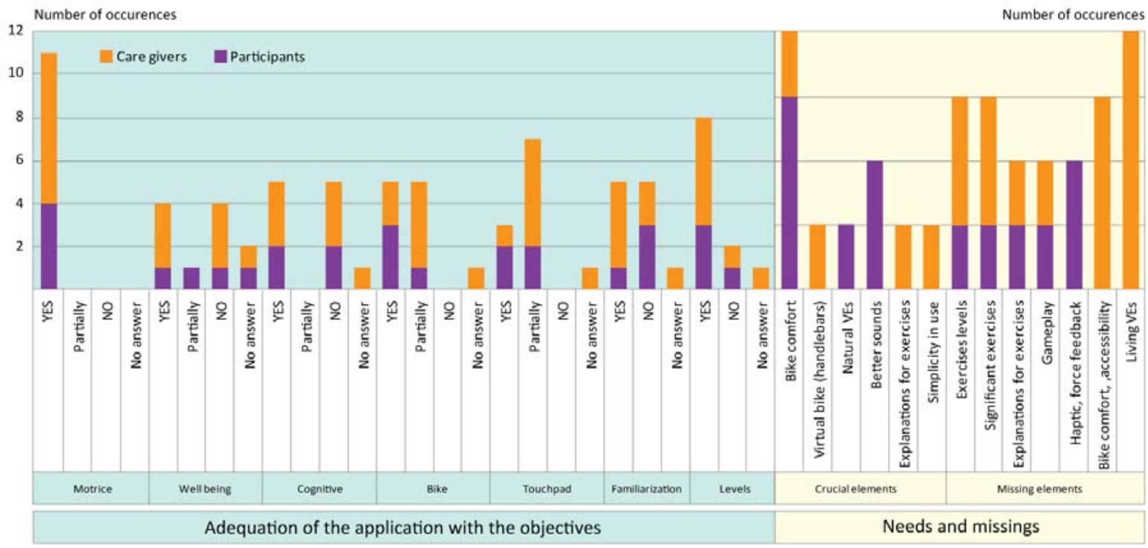

Figure 3. *Results of test A. Adequacy between the application prototype and the objectives of the project (blue section) and needs and missings encountered by the panel (yellow section).*

Let’s analyze the adequacy between the three principal objectives of the application (physical activity, well-being and cognitive stimulation of users) regarding to the feelings that had the testers during test A. We immediately see that participants and caregivers agree on their answers: when care givers have an opinion on the currently considered criterion, the participants have the same. Despite it is clear for both samples that the prototype totally fulfills its role for allowing users to have physical activity, some caregivers and participants clearly indicate that the prototype does not give any well-being to the interrogated persons. The cognitive stimulation is badly considered by some of the testers estimating that the exercises are boring and that a goal could increase the motivation of users.

Concerning the hardware part of the instrumentation, the bike is roughly appreciated by the asked persons. Some of them strengthened the lack of comfort of the bicycle saddle. Thus it can be inappropriate for the targeted audience whose persons may have difficulties making movements. The height, the size and the shape of the bicycle saddle are actually not well suited to the physical conditions of elderly people. The same observations are made for the three-buttons touchpad. This touchpad is dedicated to answering questions given in the cognitive stimulation exercises provided to testers. The essential issue is the nearness of the three colors (magenta, blue and purple are close colors as indicated by the subtractive synthesis of the magenta and the blue colors giving the purple color) which can be confusing for people who may suffer of visual impairment (Ishihara et al, 2001; Hedge and Hustvedt, 2011).

Concerning the proposed cognitive stimulation exercises, the tested panel represented by the care givers and the participants do not really agree on the utility of a familiarization or training procedure before the activity. Care givers estimate that training is necessary despite participants do not think a training session would be useful. This is probably due to the two following facts: care givers are close to the elderly people and know their deficiencies especially towards all ICT stuff; participants were essentially ICT-advised people and are not sensitive to the technological break which exists between the young population and elderly people. Finally, the caregivers strengthened the necessity of multiple levels in difficulty for the proposed cognitive stimulation exercises.

3.2 *Expectations and Omissions*

Based on their evaluation of the "Balade à l'EHPAD" application that professional care givers and participants previously made, we asked them the following questions:

- Which elements seem to be crucial in the current prototype to fit the project initial objectives?
- Which absent elements are missing for the prototype to fulfill the project initial objectives?

The participants strengthened their answers on the bicycle simulator comfort, the virtual environment content in term of 3D models and sounds. On the other hand, professional care givers were focused on the representation of the virtual bike handlebars, a kind of explanation during the cognitive stimulation exercises and usability simplicity.

Concerning the missing elements, both samples agree that a lot of work needs to be made for improving the cognitive stimulation exercises: adding difficulty levels, including ecological tasks and explanations, immersing the user into a motivating gameplay. Care givers who are aware on elderly people expectations think that the comfort and the accessibility of the bicycle simulator are missing as well as living VEs.

3.3 *Elderly People Preferences*

Professional care givers, participants and elderly people were asked for their preferences concerning the following elements:

- Which kind of places elderly people would like to visit?
- Which kind of sounds elderly people would like to see?
- Which kinds of colors elderly people would like hear?
- Which kind of physical activities elderly people would like to practice?

The results to these "test B" questionnaires are depicted on Figure 4.

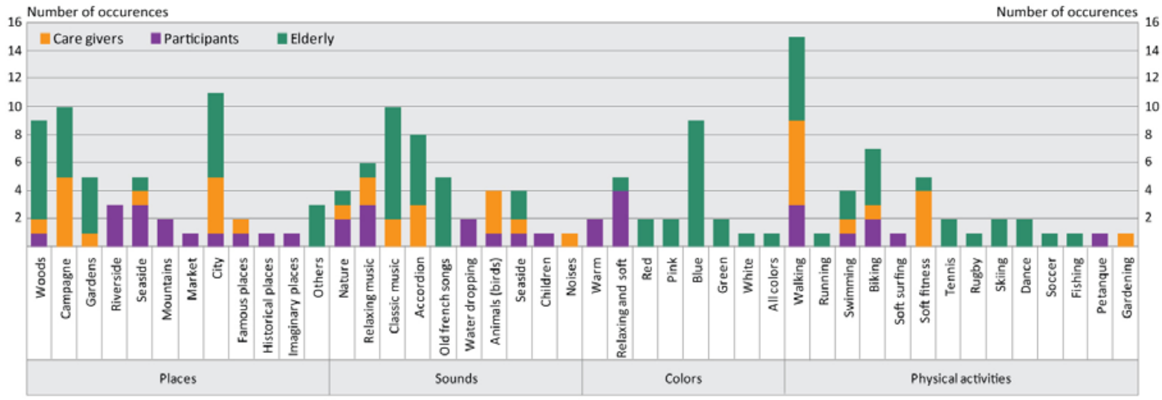

Figure 4. *Results of test B concerning the collected preferences of elderly people as questioned to professional care givers, participants and elderly people.*

Generally, professional care givers and elderly people agreed on places elderly people might like to visit, sounds they may like to hear, and physical activities they might like to practice. Notice that professional care givers did not answer for color preferences.

Concerning the places elderly people would like to virtually visit, we noticed that woods, countryside, gardens and the city are the most representative ones. Participants cited riverside, mountains, market places, famous places, historical places and imaginary places but they were not followed by elderly people themselves. This indicates that the participants sample had *a priori* concerning these preferences.

The *a priori* are much stronger when we look at the level of physical activities and colors. Concerning colors, participants estimate that elderly people would like to see warm and relaxing colors. Nevertheless, elderly people themselves prefer raw colors such as red, blue, green and so on rather than soft colors. Concerning physical activities professional care givers and participant thought that elderly people would like to be engaged in soft activities like soft fitness or aerobics, swimming, biking and walking. Actually, elderly people would like to be involved in skiing, rugby, tennis and soccer which are more violent sports. This clearly indicate that elderly people do not want to considered as other human beings able to practice equivalent physical activities.

3.4 Recommendations

Based on the results of tests A and B presented in the previous section, we proposed software and hardware design recommendations for the "Balade à l'EHPAD" application fulfill the expectations of professional care givers and elderly people. These recommendations are synthesized in Table 2.

Table 2. *List of recommendations based on the evaluation of the "Balade à l'EHPAD" application.*

Ergonomic criterion	Recommendation
Accessibility	Improve contrasts, use raw colors and increase elements sizes Design an adapted bike for disabled people
Use assistance	Preserve use context in the same application
Conventions respect and understanding	Use classical standards in UI design
Satisfaction	Improve users comfort Make the move of users in VEs more simple Increase the users motivation in participating to the exercises
User control	Check the coherence between user actions and what happened in VEs
Efficiency and simplicity	Improve the ease of use Provide a learning session to become familiar with the application
Terms used	Check that all terms used are understandable Satisfaction
Readability and perception	Improve the readability of software and hardware UI as well as exercises elements
Homogeneity	Check the coherence between buttons and instructions given to the user

We suggest increasing the accessibility of the all application by improving contrasts by using raw colors and increasing the sizes of some elements. As depicted in a lot of studies, elderly people suffer of visual impairment (Ishihara et al, 2001); the design should be adapted to this consequence of aging (Hedge and Hustvedt, 2011). This assumption is true for UI design but also for the bicycle simulator design. Using a bike bought in a traditional sport articles retailer is not sufficient for providing an adaptive solution for elderly people. We have to consider that elderly people might be equipped with a wheelchair and should be able to use the "Balade à l'EHPAD" application. On the other hand, the bike saddle should be adjustable considering that elderly people are often smaller than younger adults. It should also provide a better sustaining to avoid falls, limit their risks and improve users 'safety.

The satisfaction of the user is a crucial point in the appropriation of a new system including software and hardware parts. For this to be achieved, it is crucial to improve the user comfort by providing an adjustable smooth bike saddle. Results strengthened the fact that the cognitive stimulation exercises were boring; it is also crucial to improve the motivation of users in their participation to the exercises. Two ways were depicted: adding difficulty levels and a gameplay, make the VEs living by adding people, animations (traffic flow for cities, people on the beach for seaside VEs and so on …).

In terms of user control, we suggest to check the coherence between the user actions and what happened in the application. For example, it should be better having coherence between the bicycle rotation speed and the virtual speed of the avatar as seen on screen.

It was obvious that a training session should be implemented for the user to faster understand how to interact with the environment. This is very important to avoid the fail feeling a user may have if he did not succeed in reaching a certain place for example.

4. DISCUSSION

The present study represents the evaluation of usability of the prototype of a VR-based application combining physical activities and cognitive stimulation. This application involves the participant into a virtual bike ride in which he has to answer to simple questions. As it has already been demonstrated by several previously published studies, our discussion will not focused on the benefits of the association of physical activities with cognitive stimulation (Colcombe and Kramer, 2003; Colcombe et al, 2003; Kramer et al, 2003; Weuve et al, 2004; Hwan et al, 2005; Deary et al, 2006; Larson et al, 2006). We will focus our discussion on the methodology VR-based applications designers and developers should acquire to fulfill the expectations and needs of elderly people.

4.1 Stop considering Elderly People as "Soft People"

Therefore, as it is the case in designing products and interfaces for other audiences, the design process is emphasized when final users are involved in (Norman and Draper, 1986; Holzinger et al, 2007). The situation is not so different concerning elderly people. Our study clearly demonstrates that a lot of stereotypes are really present in younger people. As examples, elderly people are expected to like soft colors or soft physical activities and when they are asked they answer that they prefer to see raw colors and indicate that they would like to practice violent sport such as rugby, soccer or skiing. This result obtained on our study is in coherence with what showed Mitzner *et al*. They suggest that elderly people suffer of a negative image based on stereotypes. To dismiss this behavior, they suggest that involving elderly people into the design process (as it is often the case for younger adults) will allow the designers and developers to better fit their needs and expectations (Mitzner and Rogers, 2010). Moreover, studies have already suggested methods to involve elderly people and people with dementia into the design process (Lindsay et al, 2010).

4.2 Game Design and Adapted Hardware for Elderly People

One result of our study is the nature of the virtual experience proposed. It has been cited that the experience is boring, the environment is not really living and a people are lacking. We then suggest to really developing a game design for the cognitive activities proposed in the virtual experience. Game design is the process of designing the content and rules of a video game in the pre-production stage of a video game and design of gameplay, environment, storyline and characters during the production stage (Brathwaite and Schreiber, 2009). This is also true for elderly people cognitive activities such as (exer)games and it was already achieved in several studies (Ijsselsteijn et al, 2007; Facal et al, 2009). As an example, Gerling *et al* wrote several articles on (exer)game design for elderly users (Gerling et al, 2010). In addition to the adaptation of the game design to elderly people, the hardware part needs also to be adapted as depicted in this study by the fact that the bike simulator used was not adequate to allow elderly people to perform test A without any safety issues. This is also noticed in several studies using adapted Wii Balance Board (Neufeldt, 2009), Wiimote remote (Boulay et al, 2011).

4.3 Elderly People also bring their Own Background into VR Experiences

People bring their own background into a virtual reality experience. This assumption is also shown in our results in their preferences in term of environments, sounds and music and colors. As shown by North et al., it is crucial to take into account their expectations in term of design, thus improving their adherence (North et al, 1997). As mentioned by B. Lange and co-workers, the adherence to the therapeutic program will be increased if the treatment is fun, motivating and distracting (Lange et al, 2010). Wherever "Balade à l'EHPAD" is not a therapeutic application used in virtual rehabilitation, it must infer an adherence feeling for being efficient in improving quality of life, self-esteem and well-being of involved elderly people.

Finally, one important preconceived idea is that elderly people as disabled one do not care about their living environment and then can be immersed into virtual environments that do not fit to the rules of "beauty". The cognitive mechanism which causes the relationship between aesthetics and usability exists and as depicted by Ilmberger et al., "what is usable is beautiful" (Ilmberger et al, 2008).

5. CONCLUSION

We presented in this paper a usability study of the first version of the VR-based "Balade à l'EHPAD" application which is dedicated to physical and cognitive stimulation among elderly people. Our focus was on usability issues, participant interactions and behaviors. Thanks to the results, we built recommendations for improving the first version of the prototype. Our study also confirms that co-design of a VR-based application is an essential part of the design process. Designers and developers must forget all their

preconceived ideas on elderly people thoughts and listen carefully to their needs and expectations. They will bring into the virtual environments their knowledge of the world and their feelings. In a VR-based application, if the software or the hardware do not fit with these expectations, the application will never be appropriated and the objectives will not be fulfilled.

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Study of the impact of added contextual stimuli on the performance in a complex virtual task among patients with brain injury and controls

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ABSTRACT

During the last years, researchers showed the feasibility and the interest of using Virtual Reality (VR) among patients with cognitive impairments for the recovery of capacities. While interacting, the VR system provides various kinds of information for different purposes: display of the virtual environment, understanding of the task, but also highlighting of functionalities or delivery of instructions. Generally, in order to improve the patient performance, additional cues are provided to enhance information saliency, such as arrows, change of colors. We define a "contextual Additional Software Stimulus" (contextual ASS) as any additional information delivered by the virtual system, related to the interaction whose absence in the virtual environment does not have an effect on the unfolding of the task. This work was designed to study the effects of contextual ASS on the performance in a daily living simulated task: purchasing items in the Virtual Action Planning Supermarket (The VAP-S). In this purpose, we started by implementing ASS in the VAP-S then we carried out experiments in which 23 healthy subjects (12 M and 11F) and 12 patients with brain injury (12 M) took part. Results show that the deliverance of contextual ASS during the virtual task improves significantly some parameters describing the performance of healthy subject and patients with brain injury.

1. INTRODUCTION

After brain injury, cognitive rehabilitation aims to enable the autonomy of the patients in the instrumental Activities of Daily Living (iADL) (e.g., shopping, meal preparation). It refers to the therapeutic process of increasing or improving an individual capacity to process and use incoming information so as to allow increased functioning in everyday life (Sohlberg and Mateer, 1989). Executive Functions are defined as higher-order functions that are needed to perform organized goal directed behaviors. They include the capacity for initiative, formulating goals, planning, organization, reasoning, control, audit, abstract thinking and self-awareness (Meulemans, 2006). Many studies showed the feasibility and the interest of using Virtual Reality (VR) among patients with cognitive impairments for the recovery of capacities (Rizzo et al, 2004; Rose et al, 2005; Klinger et al, 2010). VR offers to the patient the possibility to experience simulated activities of daily living in which their performance in the task (e.g., cooking, shopping, road crossing, etc.) is observed and documented (Klinger, 2006a; Klinger et al, 2006; Klinger, 2008; Cao et al, 2009; Rand et al, 2009). In order to improve performance in virtual tasks, additional cues are provided to enhance information saliency, such as arrows, change of colors (Cao et al, 2010; Farran et al, 2012). We define a "contextual Additional Software Stimulus" (contextual ASS) as any additional information, delivered by the virtual system, related to the interaction whose absence of the virtual environment does not have an effect on the unfolding of the task.

A few works in the literature allow us to underline the relationship between the contextual ASS delivered by the virtual system and the performance of the subjects in the virtual task. In order to illustrate research works, we chose studies that cover both of auditory and visual modalities for the deliverance of ASS, since they represent the privileged modalities of information delivery in virtual environments (VE).

In the context of learning professional gestures, the CS WAVE was set up to train or evaluate people's welding motion skills (Mellet-d'Huart, 2002; Burkhatdt et al, 2003; Mellet-d'Huart, 2004). The CS WAVE is a virtual environment that allows the trainee to perfect his hand motion accuracy and concentration through a

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full range of exercises. It provides the trainers with an efficient support to follow-up and to assess the student evolution. It provides various guided information delivered as contextual visual ASS (texts and graphs), for example, visual marks to guide the learner not to overflow the area of welding.

Sanchez and colleagues developed the Audio-Based Environments Simulator (AbES) software that enables blind people to navigate through virtual representation of real spaces. Thanks to auditory cues, the system allows blind people to train their orientation and mobility skills in closed and unfamiliar spaces (Sanchez et al, 2009). The AbES consists of a two-floors building containing many rooms and different objects (furniture, etc.), and includes three modes of navigation and interaction: Free navigation, Path Navigation and Game Mode. In the free navigation mode, the patient explores freely the building. In the path navigation mode, the patient has to find a particular room in the building. The game mode task consists of a game in which blind participants have to find jewels and to bring them outside before that the monsters, randomly placed inside the building, steal the jewels and hide them elsewhere. Specific auditory stimuli are used to inform the blind participants about the presence of an enemy or a jewel. The system also delivers a verbalized audio of the cardinal direction of the user. When it is possible to move forward in the VE, the sound of a footstep is heard. When bumping against objects of the VE, another sound is heard indicating the collision. The system delivers also information that related to the location and the orientation of the user and about the task that must be completed. The experiments included six children (2 girls and 4 boys) whose ages ranged between 9 to 11 years old. Results show that the AbES is usable and highly understandable by blind people. The system allowed the blind participants to understand the dimensions and the spatial layout of the environment. The authors concluded that, if the users were clear on the locations of the walls and the doors, it would be possible to construct a more robust mental map of the space, allowing for a real training and rehabilitation exercise.

Cao and al. developed the Therapeutic Virtual Kitchen (TVK). The TVK is a virtual kitchen that is graphically very close to the Kerpape Center kitchen (Cao et al, 2010). Its various functionalities include behaviors of all the 3D objects that are required in coffee preparation or in the follow-up of all the activity of the participant. Coffee preparation is a complex task, including various steps that should be carried out in a correct way in order to prepare the coffee. Real sounds are provided according to the activated 3D objects, in order to increase the feeling of immersion within the virtual kitchen. During the task, contextual ASS can be provided by the therapist in order to help the participant to perform the task. These contextual ASS also bring information about the next step of the task. Besides, mouse visual stimuli are provided to facilitate the understanding of the interaction opportunities, like the modification of the mouse cursor according to user action (take, pour, activate, connect). In spite of the fact that the TVK is an VE with enriched information that provides various kinds of ASS, no work was set up, at present, to study the role of these stimuli on people with brain injury.

The quoted studies suggest the important role of the contextual ASS in the performance of subjects in the task. Let's now consider the Virtual Action Planning Supermarket (VAP-S) (Klinger et al, 2004; Klinger, 2006b) that was designed to assess and train the ability to plan and execute the task of purchasing items on a shopping list. Operating the VAP-S includes a series of actions, described as a task, and allows an analysis of the strategic choices made by clients and thus their capacity to plan, such as the "test of shopping list" (Martin, 1972). Many studies showed the efficiency of the VAP-S as tool of cognitive evaluation for different populations such as Parkinson disease (Klinger et al, 2006), mild cognitive impairment (Werner et al, 2009), and schizophrenia (Josman et al, 2009). In order to use it in cognitive rehabilitation and to provide graduated modalities of intervention, we raise the issue of information saliency within the VAP-S, and in particular saliency of the items of the shopping list. In fact, these items are not specifically striking compared with the others items of the supermarket.

The objective of this work was: 1) to implement visual and auditory contextual ASS in the VAP-S; 2) to examine their impact on the performance in a complex virtual reality based task in the VAP-S among healthy subjects and patients with brain injury.

2. METHOD

2.1 Participants

To carry out the study, we included twelve patients with brain injury (12 males, mean age = 48±12) who attended the Rehabilitation Center of Kerpape and the hospital of Bordeaux in France, and twenty-three healthy subjects (12 male and 11 female, mean age = 29±6).

All of participants were right handed and only one of them has a little experience in video games.

2.2 Instrumentation

The VAP-S was designed to assess and train the ability to plan and execute the task of purchasing items on a shopping list. The VAP-S simulates a medium size supermarket with multiple aisles displaying most of the items that can be found in a real supermarket. It was already described in previous published studies (Klinger et al, 2004; Klinger, 2006a).

Purchasing items is a complex task that involves cognitive functions such as spatial capacities, attention, or executive functions. In order to highlight the items of the shopping list, we enriched the VAP-S with an additional layer that makes it deliver visual and auditory Contextual ASS. The visual contextual ASS is “Blinking of the list items” which occurs when the participant is close to an item of the shopping list. The auditory contextual ASS is an “Alarm beep”, which occurs in the same spatial condition as the previous ones.

2.3 Procedure

Subject were given a pre-trial session to be familiarized with the VAP-S. Then, they were engaged in the assessment session in which they had to purchase two lists of items (L1 and L2) in four conditions. Both lists contain four items belonging to the same categories of products and in the same geographic locations. For each participant, the task included the 4 following conditions: 1) purchasing the items of L1 without CAS (Condition C0); 2) purchasing the items of L2 without CAS (Condition C1); 3) purchasing the items of L1 with an auditory CAS (Condition C2); 4) purchasing the items of L2 with a visual CAS (Condition C3). To avoid any effect of learning, the participants started the task either with a condition with ASS or with a condition without ASS as described in Table 1.

Table 1. *Unfolding of the test for each participant.*

P1	P2	P3	P4	P5	…
C0-C2-C1-C3	C2-C0-C3-C1	C0-C2-C1-C3	C2-C0-C3-C1	…	…

2.4 Data analysis

Descriptive data analyses were used to study the population and the main variables representing the performance. To study the signification of the differences found in the tests, we used Student’s paired t test, with a 95% confidence interval.

3. RESULTS

We describe the performance of the participants in the VAP-S task thanks to the following variables: total distance in meters traversed by the patient (D), total task time in minutes (T), number of purchased items (NbI), number of correct actions (CA), number of incorrect actions (IA), number of pauses (NbP), duration of pauses (TP) and the number of intersection points in the curves representing the trajectory of participants in the virtual environment (Intersect).

Results are described with means and standard deviations; they are collected in Table 2 for patients and in Table 3 for healthy subjects. The third column of each table contains comparisons between participants performances in the conditions C0 (list L2 without contextual ASS) and C2 (list L2 with auditory contextual ASS), illustrated by the significance of the difference (p). The sixth column of each table contains comparisons between participants performances in the conditions C1 (list L2 without ASS) and C3 (list L2 with visual contextual ASS), illustrated by significance of the difference (p).

Results show that the performance of healthy subjects was significantly better in condition C2 compared to that in condition C0:

- Decrease of the distance traversed in condition C2 (128±18 m) compared to C0 (149±29 m), (p = 0.002)
- Decrease of the total time spent in the task in condition C2 (3.3±0.7 min) compared to C0 (4±0.8 min), (p = 0.000)
- Decrease of the number and the duration of pauses in condition C2 (5±2 stops and 0.8±0.3 min) compared to C0 (7±3 stops and 1.1±0.5 min), (p = 0.051, p = 0.008)
- Decrease of the mean number of point of intersection in the curves representing the trajectory of participants in the condition C2 (1±1) compared to C0 (3±3), (p= 0.001)

The same observation is also valid passing from the condition C1 to the condition C3:

- Decrease of the distance traversed in the condition C3 (121±12 m) compared to C1 (138±17 m), (p = 0.000)

- Decrease of the total time spent in the task in the condition C3 (3.2±0.7 min) compared to C1 (3.9±1 min), (p = 0.000)
- Decrease of the number and the duration of pauses in the condition C3 (5±3 stops and 0.9±0.8 min) compared to C1 (7±4 stops and 1±0.6 min), (p = 0.097, p = 0.607)
- Decrease of the mean number of point of intersection in the curves representing the trajectory of participants in the condition C3 (1±1) compared to C1 (2±2), (p= 0.007)

Figure 1 shows two examples of curves representing two trajectories of a subject in two different conditions. The first curve, on the left, illustrates the trajectory realized in the task carried out under the condition C0. The second curve, on the right, illustrates the trajectory of the same subject under the condition C2.

Table 2. *Patients performances in the different conditions.*

Patients N= 12 (12 H)	Condition C0	Condition C2	p	Condition C1	Condition C3	p
Age	48±12	48±12	-	48±12	48±12	-
NbA	4	4	-	4	4	-
BA	9	9	-	9	9	-
DP (m)	192±65	154±48	0.042	168±47	133±33	0.002
T (min)	8.1±3.1	6.1±2.8	0.01	6.3±2.2	5.1±2.1	0.007
MA	4±4	2±4	0.036	2±4	3±4	0.389
NbP	13±6	13±9	0.9	11±4	9±4	0.083
TP (min)	2.9±1.6	2.8±1.7	0.8	2.3±1	2±1	0.164

Table 3. *Healthy subjects performances in the different conditions.*

Healthy subjects N= 23 (11 F, 12 H)	Condition C0	Condition C2	P	Condition C1	Condition C3	P
Age	29±6	29±6	-	29±6	29±6	-
NbA	4	4	-	4	4	-
BA	9	9	-	9	9	-
DP (m)	149±29	128±18	0.002	138±17	121±12	0.000
T (min)	4±0.8	3.3±0.7	0.000	3.9±1	3.2±0.7	0.000
MA	2±3	2±2	0.644	2±2	1±2	0.332
NbP	7±3	5±2	0.051	7±4	5±3	0.097
TP (min)	1.1±0.5	0.8±0.3	0.008	1±0.6	0.9±0.8	0.607
Intersect	3±3	1±1	0.001	2±2	1±1	0.007

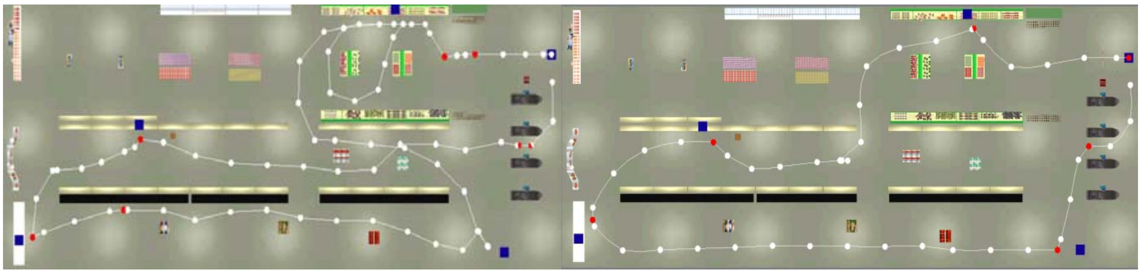

Figure 1. *Two examples of curves representing two trajectories of a subject in the conditions C0 (on the left) and C2 (on the right).*

The comparisons show that the performance of healthy subjects was actually better when they performed the task assisted by the delivery of contextual auditory and visual ASS. In fact, once assisted by stimuli,

participants executed the task faster, crossed a shorter distance, made less incorrect actions and made less stops than unassisted participants.

This result is confirmed by the fact that 21 out of 23 subjects, considered that the contextual ASS delivered during the task helped them to better perform the task. Only 2 subjects felt that the delivery of the stimuli had no effects on their behaviors in the task. On the other hand, no subject considered that the delivered ASS disturbed him or that they had a negative effect on his behavior during the task.

The same observations are almost valid for patients whose performance was better in the condition C2 and C3 compared respectively to the conditions C0 and C1. In fact, they executed the task more rapidly and traversed a shorter distance in the conditions C2 and C3:

- Decrease of the distance traversed in condition C2 (154±48 m) compared to C0 (192±65 m), ($p = 0.042$)
- Decrease of the total time spent in the task in condition C2 (6.1±2.8 min) compared to C0 (8.1±3.1 min), ($p = 0.010$)
- Decrease of the mean number of point of intersection in the curves representing the trajectory of participants in the condition C2 (2±1) compared to C0 (4±4), ($p= 0.094$)
- Decrease of the distance traversed in the condition C3 (133±33 m) compared to C1 (168±47 m), ($p = 0.002$)
- Decrease of the total time spent in the task in the condition C3 (5.1±2.1 min) compared to C1 (3.9±1 min), ($p = 0.007$)
- Decrease of the mean number of point of intersection in the curves representing the trajectory of participants in the condition C3 (1±1) compared to C1 (2±2), ($p= 0.007$)

Thus, when they are assisted by visual and auditory ASS, patients execute the task faster and traversed a shorter distance. This increase in the performance of patients when they are assisted by contextual ASS is confirmed by the fact that 10 patients out of 12, considered that the contextual software stimuli delivered during the task helped them to better perform the task.

4. DISCUSSION

In this study, we wanted to assess the effect of contextual ASS on the performance in a simulated instrumental activity of daily living: a shopping task in the VAP-S. The experiments we carried out suggest that the contextual ASS delivered by the virtual system during the task have some potential effect. Indeed, when they were assisted by the contextual ASS, participants in both of populations performed the task more rapidly, traversed a shorter distance and found easier the virtual targets. Then, better performance can be achieved by assisting users using contextual visual and auditory software stimuli.

That was confirmed by the fact that about 93% of healthy subjects and 80 % of patients considered that the delivered software stimuli helped them to better perform the task and the rest of participants considered that it had no effect on them.

Besides, participants were not informed about the relationship between the delivered software stimuli and the virtual scene. This suggests that if participants were explicitly told about this relationship, their performance would have been better than that found in the experiments. We also compared our two groups of participants, and significant performance differences appear between the healthy subjects and the patient groups. But these results are not evoked in this paper because the two groups are not matched in age.

The results found cope with those of other works carried out in the context of spatial orientation tasks and object manipulation tasks. They prove the helping role of the contextual ASS for healthy subjects and patients with brain injury when performing virtual tasks.

5. CONCLUSION

Thanks to this work we succeeded in developing contextual stimuli in the VAP-S that had an effect on some parameters of the performance in the virtual shopping task. Healthy participants and patients with brain injury performed the task more rapidly, crossed a shorter distance and found easier the virtual targets. Nevertheless, the threshold of contextual ASS beyond which the performance starts to decrease is not specified in this work. In fact, stimuli which are source of information may also be source of confusion and disturbing if they are delivered in too big quantities. This issue is part of our future work

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Development of the system for continuous medical rehabilitation for patients with post-stroke and spinal cord injury motor disorders

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ABSTRACT

This paper describes an experience of developing a computer system for continuous medical rehabilitation involving patients with post-stroke and spinal cord injury motor disorders. Particular focus is made on the concept of telerehabilitation for this specific group of patients. Telerehabilitation has to be continuous and regular. It is also necessary to provide the possibility of conducting treatment/communication sessions asynchronously. The empirical results of four year implementation of this system in Russia showed high efficiency and revealed some limitations of a distant network rehabilitation program based on electromyographic biofeedback.

1. INTRODUCTION

In Russia every year around 0.5 million patients after cerebral accidents and 0.5 million patients with severe brain injuries are registered. 40% of them are in age of capacity, but their ability to move is restricted. The efficiency of medical rehabilitation for spinal cord injury (SCI) and stroke patients greatly depends on the availability of regular rehab procedures for a long-time period. Regretfully, the majority of high-tech methodologies are located in a limited number of neuro-rehab centers which are not able to provide proper medical assistance because of their fewness and financial pressure. The lack of permanent medical assistance results in poor rehabilitation outcome. To increase the effectiveness of medical rehabilitation, it obviously has to be continuous and regular. The attempts to extend the care possibilities to the patient's home are so far limited, focusing mainly on tele-monitoring, tele-diagnosis, and limited tele-assistance.

The concept of telerehabilitation states that the therapy is provided remotely. Ideally, the patient should be able to receive the majority of his/her treatment at distance, at home. The advantages are clear: familiar environment ideally supported by family members, treatment accessible to those patients who either would not tolerate hospital care or are unable to commute to the specialized institutions (for a lack of mobility or financial reasons).

On the other hand, shortening the hospital staying brings non-trivial cost savings for the healthcare system as well. In this case the new possibilities emerge for delivering high quality rehabilitation services to a much larger population for much longer periods of time, resulting in significant improvements of the functional abilities of users.

Today there are some inexpensive apparatus intended for in-home use, among them Foot Mentor, Hand Mentor of Kinetic Muscles Inc. (USA), Balance Trainer of Medica Medizintechnik GmbH (Germany) which enable a large variety of exercises, and all of them provide various types of visual feedback (force, position, electric activity of muscles).

The principal aspect, which should be ensured during in-home rehabilitation is providing a total safety of a patient and securing sufficient level of professional control of the training process. Furthermore, it is necessary to provide the possibility of conducting séances (treatment/rehabilitation sessions) asynchronously, that is to separate in time a doctor’s recommendations for home training, the fulfillment of these recommendations by a patient, and the analysis of results.

Speaking of telerehabilitation where the procedure is provided remotely, it is conventionally implied that a rehab specialist and a disabled individual keep online contact all the time. If there is no need for both of them to be present in the network, then the rehabilitation, control and correction course can be organized with greater flexibility. In this way any issues related to the synchronizing of client's and specialist's work can be ignored. Actually, the organization of telerehabilitation online sessions for greater numbers of disabled clients may bring in the problem of scheduling the rehabilitation. Online sessions can be conducted from time to time to monitor complicated cases.

To meet these requirements we have decided to apply electromyographic biofeedback technology and implement data exchange via remote web-server. It is worth mentioning that all modern high-tech neuro-rehabilitation technologies, such as: Neuro-Robotics, Neural Prostheses, and Virtual Rehabilitation (BCI), use various types of feedback, biological feedback is among them (Chernikova, 2007).

2. METHODS

2.1 EMG Biofeedback

The biofeedback method uses signal processing devices to provide a patient in real time with meaningful information (auditorial or visual) about the changes of a certain physiological signal, such as heart rate, temperature, muscle tension and brain rhythms. With this information, and guided by the biofeedback therapist, the subject has the possibility of altering these physiological signals, changing them to a more desirable level by practicing special self-regulation techniques. The aim of biofeedback-based training is to increase awareness and to facilitate voluntary control of physiological processes that a person is not aware of. Additionaly, the aim is to motivate learning of effective behavioral patterns that would prevent, eliminate or reduce symptoms. According to the principles of biofeedback technology, instead of being a passive object of the rehab procedures a patient becomes an active participant of treatment (Shtark and Shwartz, 2002).

The electromyographic (EMG) biofeedback involves measuring the electric activity of the muscles which expresses their degree of contraction/relaxation. EMG biofeedback is used in many clinical and biomedical applications as a diagnostic tool for identifying neuromuscular diseases and is targeted as a control of muscle activity in motor disorders rehabilitation.

The use of the biofeedback computer system allows registering and monitoring the muscle tone. The dynamics of the EMG signal is viewed on a computer screen so that the patient is able to assess his/her own muscle tension and increase/reduce muscle efforts to achieve the goal of training or "threshold" (Fig. 1, 2). Consequently EMG biofeedback helps improve motor functioning.

The advantages of biofeedback-based rehabilitation include: quantitative evaluation of the results, monitoring of the signal dynamics, supervising of training progress, control of pathological deviations of physiological functioning and automatic session break if a patient has got tired, independently of rehab specialist presence.

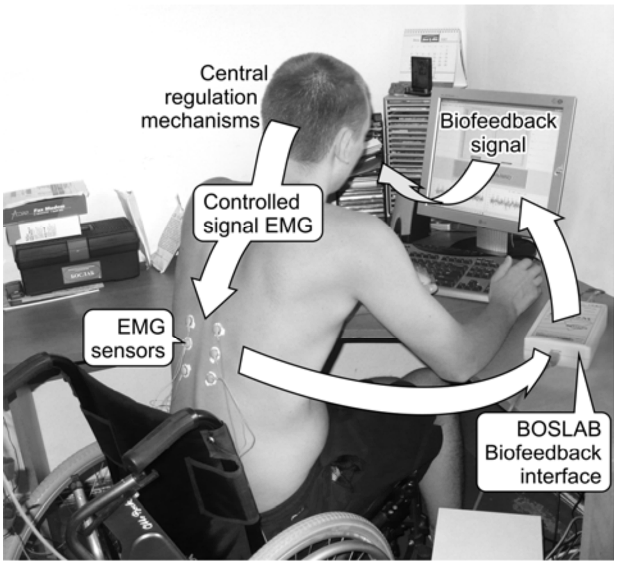

Figure 1. *The biofeedback loop. An example of EMG biofeedback session* [Guk et al, 2010a].

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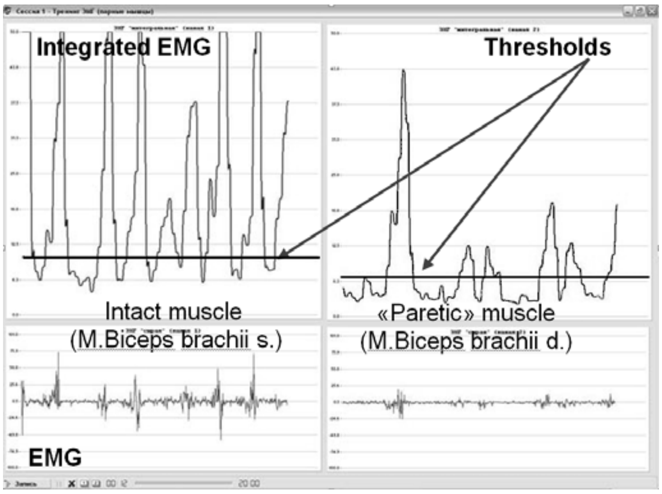

Figure 2. *EMG biofeedback training screenshot. When integrated EMG (calculated from raw EMG signal) is above the threshold audio feedback signal sounds, for each channel its own.*

The following biofeedback equipment was used: computer system BOSLAB with BI-12 module of 2 EMG and 2 temperature channels (EC conformity declaration CE № 01052008/K, Russian Registration Certificate №FSR 2011/11236 and Russian conformity certificate №POCC RU.AЯ79.B15475) and PC Windows XP/Vista with Internet connection.

Monitoring a fatigue during biofeedback sessions was carried out by monitoring the skin temperature of the trained limb ("target"). As the decrease of temperature means there is an increase of fatigue, so the patient takes a short rest.

The average training session consisted of 2-3 sessions of working with various muscle groups, the total duration was 20-30 minutes.

The use of the game forms of biofeedback EMG training (Fig.3) featuring players' ratings, morphing, augmented reality (Fig. 4) and other modern media does indeed enhance motivation of the patient and actively involves the mechanisms of individual's self-improvement.

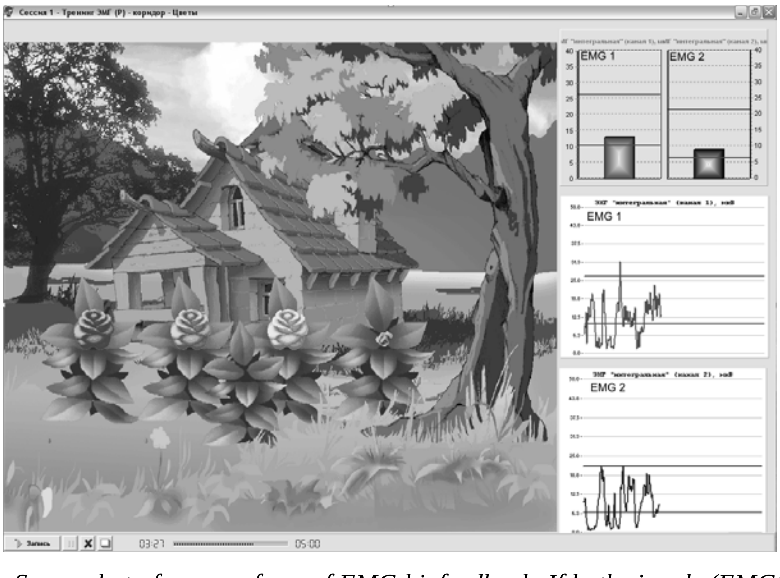

Figure 3. *Screenshot of a game form of EMG biofeedback. If both signals (EMG1 and EMG2) lie in the range between the thresholds in so called target zone a flower grows and blooms.*

2.2 Network Neuro-Rehabilitation System

To provide the system of continuous distant medical rehabilitation the following structure of network rehab has been applied (Guk et al. 2010a):

- While in a hospital or in a rehab center, a patient masters the required program of rehabilitation and gets the necessary skills and further instructions to continue practicing at home.

In particular, the doctor defines in what muscle group the decrease of strength resulted in a considerable impairment of patient's motion (e.g., if a patient had a decrease of strength of the hand's extensor muscles, the electrodes were attached to the motor points of the hand's extensor muscles; if the decrease of strength was determined at the knee extensor, the electrodes were attached to the motor points of the quadriceps muscle, etc.) The doctor uses BOSLAB program to create a treating séance that consisted of set of sessions. After the séance has started, the patient alternately tenses and relaxes target muscles trying to perform the movement which is typical for this muscle group.

- At home a patient continues practicing rehab procedures independently or with the help of family members, regularly sending out training reports and data to the server via Internet, where the therapist (neurologist, rehab specialist) views and analyzes them, and come up with the task for the next training session (Fig. 5).

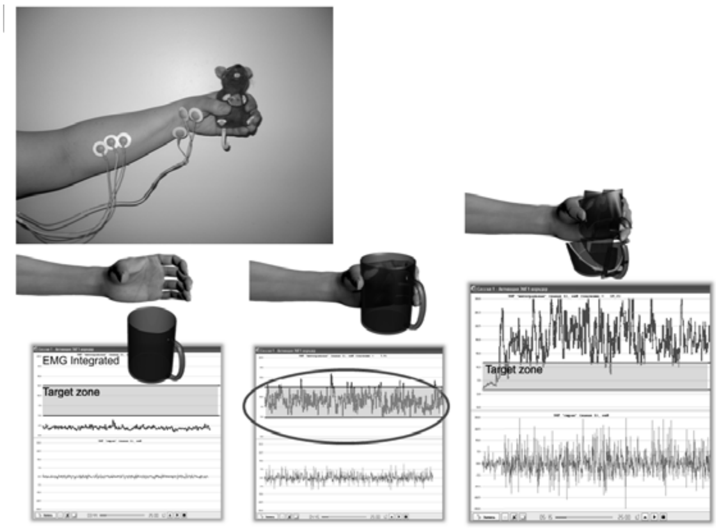

Figure 4. *Movements' coordination in physical space realized in virtual reality software based on EMG biofeedback. To improve the muscle sensitivity of a hand it is necessary to maintain a certain level of muscle tension precisely in forearm and hand to take and hold a cup or a pen, not too hard and not too loose.*

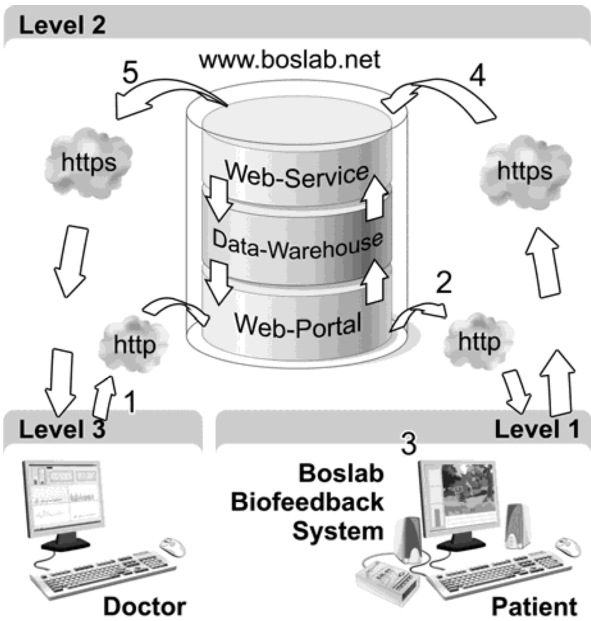

Figure 5. *Doctor-patient interaction. 1 – A doctor creates a task and uploads it to the server. 2 – A patient at home receives a task. 3 – EMG biofeedback session. 4 – The patient sends the results of the training session to a data storage. 5 – The doctor receives and analyzes the patients' data.*

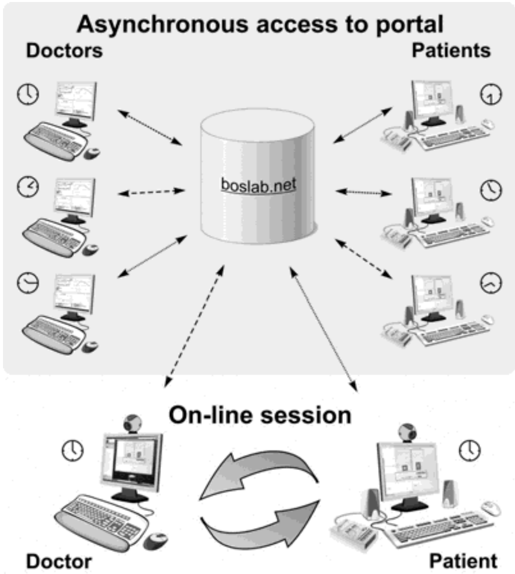

Figure 6. *Off-line and real-time (on request) operational regimes of the system.*

All system components of the system divided into the following three levels:

- *The first level* (patient's computer) is represented by the sources of data: Internal recording systems: hardware and software complexes for multichannel monitoring and biofeedback; applications for primary analysis, purification and compression of the data.
- *The second level* is represented by distributed data warehouse that also contains the operational management and analysis. It involves either a single server or a local high-speed network of servers with installed software packages for database management.
- *The third level* is represented by a set of applications for data analysis and reports, for remote monitoring of the rehabilitation process by a rehab specialist: statistical comparison of training effectiveness.

In the structure described above, there is no need shown for a rehab specialist and a patient to conduct the training sessions in a teleconference regime, therefore the schedule of the process is assumed to be more convenient for both a doctor and a patient. The network rehabilitation system may involve unlimited number of users, considering the sensible organization of the work of rehabilitation specialist. Teleconferences with patients can be conducted if needed (to control placement of the electrodes and quality of oscillatory process during training session, to eliminate interference and to control exercise performing) (Fig. 6).

2.3 Experimental Group and Procedure

Since 2007 the Siberian Clinical Centre FMBA (Krasnoyarsk) has been a clinical base of the project. There were 30 post-stroke patients, 43 patients with SCI consequences who manifested severe motor disorders/ They took part in the study. The participant requirements for the project were: normal cognitive functioning and ability to learn. Control group consisted of 35 disabled in-patients of the Siberian Clinical Centre FMBA with motor disorders of the same origin who were examined in 2011-2012.

At the first stage the patients underwent 5 to 10 sessions of EMG biofeedback at the hospital to get the required training skills. The choice of training type depended on the clinical picture of the disease. Patients with high muscle tone underwent the treatment of excessive spasticity, mainly aimed at spastic muscles' relaxation and the rest practiced increasing muscle strength.

Later at home they continued practicing muscle activation and relaxation exercise 3 to 5 times a week during 2 to 4 months, depending on the severity of the cases and the level of affection, using distant network neuro-rehabilitation.

Testing was conducted at the end of staying in a rehabilitation center and after the distant rehabilitation, which usually coincided with the rehospitalization. For the control group the testing was performed at the end of the period of staying in a rehabilitation center and before the next hospitalization. We used the following scales: Modified Ashworth Scale for Grading Spasticity, Barthel ADL Index, Motor and Sensory Examination of ISCSCI-92.

3. RESULTS

The research conducted in 2007-2011 has demonstrated improvements in the dynamics of EMG such as stable increase in EMG amplitude of the trained muscle group during biofeedback sessions that resulted in the higher muscle strength, increased limbs' circumference and joint range of motions. Additionally, it resulted in improvement (recovery) of the superficial sensitivity at 2-4 segments, and change of the deep sensitivity (sense of pressure, muscular sense) (Guk et al, 2010a,b).

Average duration of the distant rehabilitation course was 3 months for post-stroke patients and 4.5 months for SCI. The example of the dynamics of EMG of a post-stroke patient is shown on Fig. 7A. The distant rehabilitation course lasted 2 months. The motor dysfunction of the case shown at Fig.76B was more severe (L1, lower paraparesis) and the duration of rehabilitation was more than 5 months.

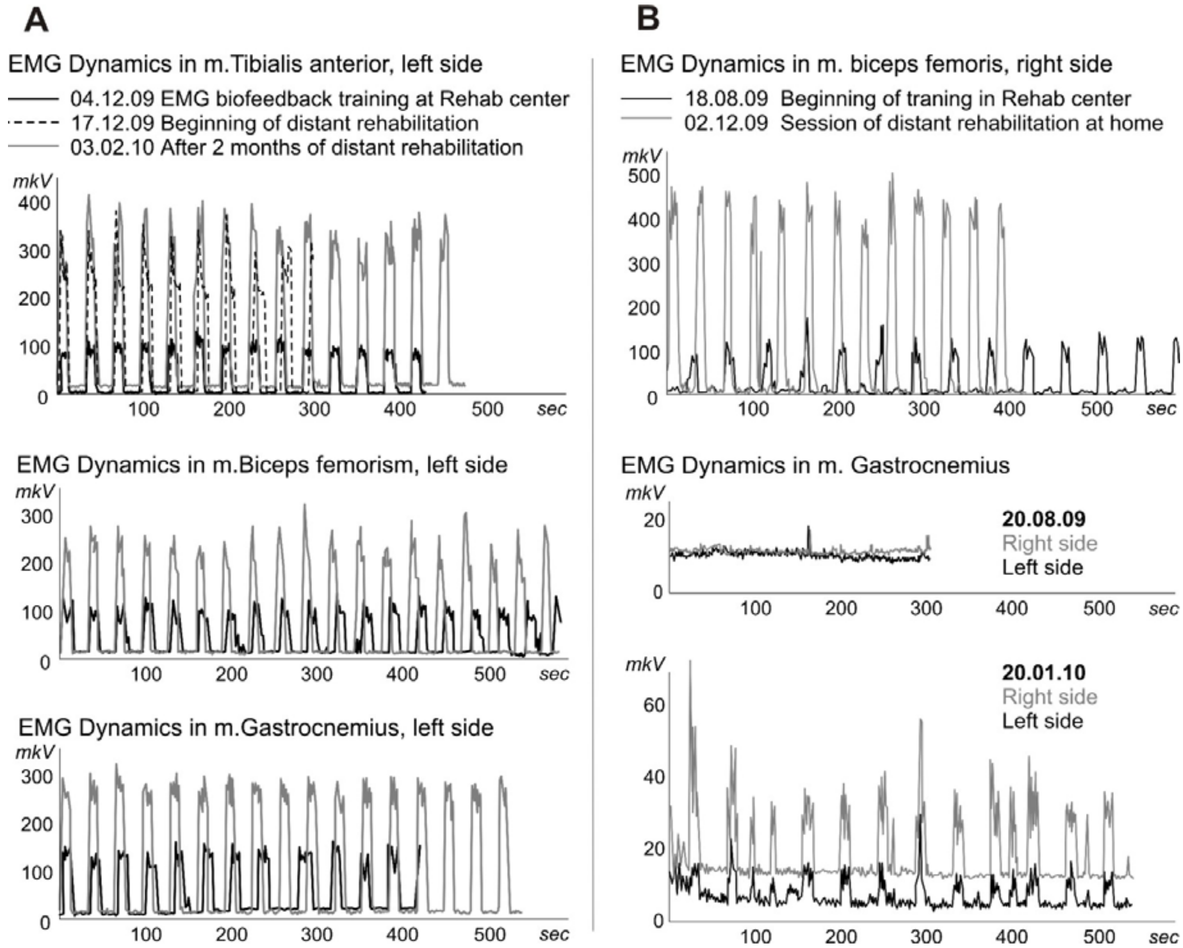

Figure 7. *Examples of network rehabilitation dynamics*: *A - Patient V., 50 years. Post-stroke. Left-side hemiparesis; B - Patient M., 21 years. L1. Lower paraparesis.*

It was discovered that stable increase in the amplitude of EMG registered at the trained muscle group during the first 10-20 training sessions can be regarded as positively prognostic.

The results of patients' examination before and after distant rehab showed that for the patients with increased spasticity the efficiency of biofeedback training was less pronounced (Table 1). This could be due to their low motivation related to the relaxation training, as these patients wanted to improve their movement ability and increase self-service, for which purpose they thought it was expedient to practice muscle activation, not relaxation. Therefore we believe that for patients with increased muscle tone the biofeedback relaxation training at home should be more exciting, with a sufficient motivational component.

In our study, during the relaxation training, the patient tried to relax muscles and increase the skin temperature, at the same time trying to keep the EMG signal on the monitor lower than the threshold set by the program. Upon reaching the required level of muscle relaxation a movie or slide show could be viewed without distortion, the flowers were growing, the mosaic pictures were opening. Unfortunately, the authors of the project do not have other options to offer for this target group.

Table 1. *Dynamics of patients' condition during network neuro-rehabilitation course (M, scores).*

	ISCSCI-92 Motor Examination		ISCSCI-92 Sensory Examination		Barthel ADL Index		Ashworth Scale	
	Before	After	Before	After	Before	After	Before	After
Group of low spasticity (N=56)	75.12	78.00 **p=0.000**	190.46	192.3 **p=0.028**	77.61	87.20 **p=0.000**	0.63	0.50 p=0.225
Control subgroup of low spasticity (N=27)	76.24	76.16 p=0.361	185.61	187.13 p=0.078	76.93	73.11 p=0.265	0.65	0.70 p=0.184
Group of high spasticity (N=17)	50.71	52.00 p=0.109	151.14	152.86 p=0.109	69.00	62.86 p=0.423	3.00	2.57 p=0.109
Control subgroup of high spasticity (N=8)	61.43	55.72 **p=0.004 decline**	168.00	169.13 p=0.230	71.87	73.22 p=0.357	3.00	2.85 p=0.428

p – level of significance, Wilcoxon matched pairs test.

The use of the immersive virtual / augmented reality (i.e. traveling in a virtual world like "Second Life") that allows to control the game using physiological functions aiming to relax muscle, is still a challenge. The most famous training set to develop the skills of self-control, «The Journey to the Wild Divine», «Wisdom Quest», implemented as a classical 3D computer game, uses cardio intervals and skin conductance, but not muscle characteristics, to control the Oriental mystical themes of the games.

It should be noted that the participants of the project in addition to the main myographic biofeedback training also conducted the biofeedback training based on cardio intervals control that involved competitive game subjects using Russian complex "BOS-Pulse". The training was aimed to improve the emotional condition, reduce anxiety, learn self-control, but these data are not included into the present study.

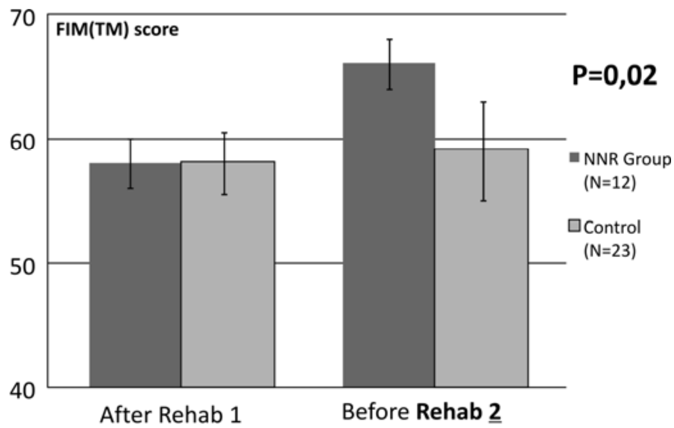

Figure.8. *Functional Independence Assessment using FIM™ scale with and without network neuro-rehabilitation. Rehab1 and Rehab2 – two subsequent courses of rehabilitation in specialized center.*

We studied the results of the network rehab course of the subgroup of 12 SCI patients during their secondary hospitalization (NNR Group). We have compared them to the control group with similar diagnosis and disease severity using the FIM (Functional Independence Measure) scale. The results shown in Fig. 8 confirmed the effectiveness of the distant medical rehabilitation program.

4. CONCLUSIONS

The project was implemented for the first time in Russia by the Institute for Molecular Biology and Biophysics of the Russian Academy of Medical Sciences (RAMS) jointly with Siberian Clinical Centre FMBA and the “Biofeedback Computer Systems Ltd.” company. The project brought to relity the possibility of providing a continuous course of medical rehab of the patients with post-stroke and spinal injury disorders. As a result, the system for acquisition, management, and storage of physiologic data and other parameters obtained during the biofeedback training has been created, including software and hardware “BOSLAB-Patient” and “BOSLAB-Doctor“ that provided advanced analytical processing of data and presenting the results of processing using a detailed and comprehensive analysis of information at both regional and national levels.

The system can provide benefit for the patients with severe motor disorders as regular treatment and rehab procedures can be conducted not only in hospitals, but also at home to secure a constant contact between patients and rehab specialist who organizes and controls the process of rehabilitation, which is very important to increase its efficiency.

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Improving orientation and mobility skills through virtual environments for people who are blind: past research and future potential

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ABSTRACT

This presented paper describes and examines 21 virtual environments developed specifically to support people who are blind in collecting spatial information before arrival at a new location and to help people who are newly blind practice orientation and mobility skills during rehabilitation. The paper highlights weaknesses and strengths of virtual environments that have been developed in the past 15 years as orientation and mobility aids for people who are blind. These results have potential to influence future research and development of a new orientation and mobility aid that could enhance navigation abilities.

1. INTRODUCTION

A basic task such as navigation requires a coordinated combination of sensory and cognitive skills. Unfortunately, people who are blind face great difficulties in performing such tasks. Research on orientation and mobility (O&M) skills of people who are blind in known and unknown spaces (Passini and Proulx, 1988; Ungar et al., 1996) indicates that support for the acquisition of spatial mapping and orientation skills should be supplied at two main levels: perceptual and conceptual. In this paper we use the term O&M to refer to "the field dealing with systematic techniques by which blind persons orient themselves to their environment and move about independently" (Blasch et al., 1997). At the perceptual level, information perceived via other senses should compensate for the deficiency in the visual channel. Thus, the haptic, audio, and olfactory channels become powerful suppliers of information about unknown environments. At the conceptual level, the focus is on supporting the development of appropriate strategies for an efficient mapping of the space and the generation of navigation paths. According to Jacobson (1993), people who are blind tend to explore the indoor environment through a perimeter-recognition strategy, followed by a grid-scanning strategy.

Over the years, secondary O&M aids have been developed to help people who are blind explore real spaces. There are currently more than 146 O&M electronic systems and devices (Roentgen et al., 2008). These secondary aids are not a replacement for primary aids such as the long cane and the dog guide. We can divide these aids into two groups: (i) preplanning aids provide the user with information before arrival in an environment, for example verbal description, tactile maps, physical models, digital audio, and tactile screens; and (ii) in-situ aids provide the user with information about the environment while in the space, for example obstacle detectors, tactile vision substitution system, embedded sensors in the environment, and Global Positioning Systems (GPS). There are a number of limitations in the use of these preplanning and in-situ aids. For example, the limited dimensions of tactile maps and models may result in poor resolution of the provided spatial information, there are difficulties in manufacturing them and acquiring updated spatial information, and they are rarely available. Because of these limitations, people who are blind are less likely to use preplanning aids in everyday life. The major limitation of the in-situ aids is that the user must gather the spatial information in the explored space. There is also a safety issue, since the in-situ aids are based mostly on auditory feedback, which in the real space can reduce users' attention and isolate them from the surrounding space.

Using virtual environments (VEs) has the potential to improve the ability of people with sensorial, physical, mental, and learning disabilities (Schultheis and Rizzo, 2001; Standen et al., 2001). Interaction in the VE by special needs populations presents both benefits and limitations. The benefits of the VE mainly include the user's independent interaction and activity in the VE. Users receive immediate feedback suiting their sensory and cognitive abilities. The VE allows the user to practice without fear, time limitations, or the

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need for the participation of a professional. In addition, the VE technology allows the professional to manage the amount of information and sensorial stimuli that users receive during their interaction within the VE. These unique capabilities of the VE technology system fulfill the need to design a flexible and adaptive learning or rehabilitation program for each client according to his or her special needs and abilities. Moreover, the VE technology can assist professionals in gathering information about their clients' interactions, which can assist in designing future learning and rehabilitation programs. On the other hand, the VE has some limitations. The VE is not a replica or replacement for real space interactions and activities. Furthermore, most rehabilitation centers and schools cannot afford these expensive technologies. Additionally, some systems under development are still too heavy, bulky, or complicated for use outside the laboratory environment.

Technologically advanced virtual devices enable individuals who are blind to learn by using haptic and audio feedback to detect artificial representations of reality. The most recent generations of haptic devices transmit feeling through direct contact with the virtual object (e.g., SensAble Phantom Desktop, Immersion Corp.'s CyberForce, Novint Falacon, and Nintendo's Wii). Stemming from the development of these devices, applications have been researched and developed especially for people who are blind, including identification of texture and shape recognition (Semwal and Evans-Kamp, 2000; Sjotrom and Rassmus-Grohn, 1999), mathematical learning environments (Karshmer and Bledsoe, 2002; Yu et al., 2001; Van Scoy et al., 2000; Van Scoy et al., 2005), and acquisition of spatial information.

This paper describes and examines VEs that have been developed to enable people who are blind to improve their O&M skills. There are mainly two groups of VEs: (i) systems that support the acquisition of a cognitive map (Evett et al., 2009; González-Mora, 2003; Iglesias et al., 2004; Kurniawan et al., 2004; Lahav and Mioduser, 2004; Lahav et al., 2011; Lécuyer et al., 2003; Max and González, 1997; Merabet and Sánchez, 2009; Ohuchi et al., 2006; Pokluda and Sochor, 2003; Sánchez and Lumbreras, 2000; Simonnet et al., 2010; Torres-Gil et al., 2010; Zelek et al., 2003); and (ii) systems that are used as O&M rehabilitation aids (D'Atri et al., 2007; González-Mora et al., 2006; Inman et al., 2000; Lahav, et al., 2011; Lécuyer, et al., 2003; Max and González, 1997; Seki and Ito, 2003; Seki and Sato, 2011; Tzovaras et al., 2004).

2. METHOD

2.1 Sample Selection

This study analyzed 21 peer reviewed papers selected based on research topic: VE, for people who are blind, on O&M as subject matter. The first group of papers was found by search engines for scientific journals and conferences, other papers were selected through snowball sampling, using the bibliography items to find other papers. No papers were excluded on the basis of methodological or result quality.

To assess the validity of the database, three evaluators (researcher and two graduate students) analyzed all the papers. Each paper was analyzed twice. Each of the two graduate student evaluators received 11 papers, randomly selected from our list, to be characterized according to the variables. To maximize the common framework of analysis, the graduate student evaluators and researcher met several times to discuss the variables and experimentally apply them to a number of papers. The author and two evaluators coded all 34 questions. Interjudge reliability was 97.4% and therefore regarded as valid.

2.2 Variables

Our evaluation characterized 34 variables in three main dimensions:

- *Descriptive Information Dimension.* This dimension included basic information regarding the paper and research, such as year of publication, researcher affiliation, researcher discipline, state, and source of funding).
- *System Dimension.* This dimension included four categories: (i) System features included six variables, such as system type (software and hardware), system developments' stage (prototype and shelf product), number of users (single and multiple), location (local and remote), system modality (haptic, audio, multimodal haptic, and audio), and user's input and output device (tracking system, joystick, game controller, Phantom, keyboard, head-mounted display, headphones, loudspeakers, etc.). (ii) Haptic feedback included two variables: type of haptic feedback (thermal, vibration, texture, stiffness, dumping, collision, and gravity) and variety of haptic feedback. (iii) Audio feedback included two variables: audio system (mono, stereo, and surrounding) and type of audio feedback (oral virtual guide, user footsteps, echo location/obstacle perception, and sound localization). (iv) Interaction type included four variables: user interaction (user device, body movement and user

device, and body movement), virtual object type (static, dynamic and static and dynamic), operation of the virtual object (rotation), and allowing scaling (increase or decrease object or area size).

- *Research Dimension.* This dimension included five categories: (i) Research type included three variables: clinic research; type of research (preliminary and usability), and research goal (acquire cognitive map, O&M rehabilitation trainee). (ii) Participant category included four variables: participants' visual ability, number of participants, age, and gender. (iii) Target space category included three variables: VE representing real space, space complexity (simple and complex), and space location (indoor, outdoor). (iv) Research task category also included four variables: length of exposure to VE, type of exploration, construction of cognitive map after exploring VE, and orientation tasks in the real space. (v) Data collection this category included only one variable: whether the developed system included a user log.

2.3 *Collecting Data Instrument*

For the collection of the data we used a protocol research that included all the research categories and variables described above.

2.4 *Procedure*

This study included three stages. At the first stage the researcher collected the peer review target papers using academic search engines; other papers were selected through snowball sampling. In the second stage a protocol research was developed, which included all the research categories and variables. During the third stage the researcher and two graduate students analyzed each paper twice according to the research protocol.

2.5 *Data Analysis*

To evaluate the research papers we used spreadsheet (Excel) and SPSS software mainly for cross-tab analyzing.

3. RESULTS

The research results are described below along the three research data dimensions.

3.1 *Descriptive Information Dimension*

The first paper was published in 1997 (Max and González, 1997). Most of the researchers were from academic institutions (82%); only 43% of the groups included interdisciplinary researchers, such as technology disciplines (e.g., computer science, engineering, and industrial science), social sciences (e.g., education, psychology, and rehabilitation), and from the health sciences (e.g., medicine, neuro-psychobiology, and physical therapy). Most of the paper authors were from the EU research community (67%). Worldwide, governments are the major funders (62%) with only 10% of funding from private industrial companies.

3.2 *System Dimension*

Most of the research groups developed software and used shelf hardware (77%). All VEs were developed through the prototype stage and were targeted to single users in a local mode. The most frequent system modality was auditory (53%); 43% of the VEs were multimodal (audio and haptic). Per examination of input and output user devices, users operated one or more devices, e.g., tracking system (48%), joystick (15%), game controller (15%), Phantom (19%), keyboard (29%), and head-mounted display (15%). Ten VEs integrated haptic feedback and used one or more types of haptic feedback. Ninety-five percent of the VEs included audio feedback, 40% integrated a surrounding audio system, 25% used a mono system, and only 15% included a stereo system. In type of audio feedback, 85% used sound localization, 40% echolocation and obstacle perception, 20% user footsteps, and 15% oral virtual guide. The interaction type analysis shows that most of the virtual components were static (91%); very few VEs allowed the users to manipulate the VE's objects or its space.

3.3 *Research Dimension*

Most papers included clinical research (82%), while 67% had preliminary research and 29% described usability experiments. Seventy-two percent of the research included people who were congenitally blind and late blind in their research; however 24% of the research included sighted participants who were asked to use

blindfolds during the experiments. Less then half of the examined papers (43%) included fewer than ten participants in their research. Sixty-seven percent of these research participants were adults. The VEs represented real spaces (67%), simple spaces (67%), and indoor areas (82%). Most of the simple spaces were represented in the auditory modality systems, unlike the multimodal VEs, which represented mainly complex spaces. The research results confirm the potential and the effectiveness of VEs as O&M aids. In all the clinical research, participants were asked to explore the new space by using the VE systems. These results show that most of the participants (60%-100%) explored the VE successfully. Some of the VE systems used a haptic device, such as a virtual cane (D'Atri et al., 2007; Lahav and Mioduser, 2004; Lahav et al., 2011; Lécuyer et al., 2003; Pokluda and Sochor, 2003; Tzovaras et al., 2004). These research participants reported that the different virtual canes were useful for active exploration and as passive guidance. On the other hand, some of the participants reported that they disliked being moved passively by the virtual cane (Pokluda and Sochor, 2003). Only one system included fly mode, and its users were able to determine height by the height of the directional beacons (Max and González, 1997). Nevertheless, most of the researchers noted that the avatar speed motion in the VE was necessary to meet the individual needs. Furthermore, Seki and Sato (2011) found that the difference in stress pulse ratio in the virtual training group improved in terms of walk stress, as it did also in the real space participants group. They suggested that the VE was perceived by the user as a safe training environment and thus it could reduce the stress experienced by the novice trainee, as opposed to the stress experienced in training in the real space. Furthermore, the results found by Ohuchi et al. (2006) showed that participants' physically turning right or left in a multimodal VE caused disorientation. The multimodal systems mostly focused on acquiring a cognitive map. Accurate spatial descriptions of the explored spaces were given after exploring the VE (Evett et al., 2009; Lahav and Mioduser, 2004; Lahav et al., 2011; Max and González, 1997; Ohuchi et al., 2006; Pokluda and Sochor, 2003). The participants were able to simulate the environment size differences successfully (Kurniawan et al., 2004; Tzovaras et al., 2004). Similar results were found among adults and children who were totally blind or had residual vision, but different results were found among children with residual vision and medium cognitive achievement,who were unable to create a spatial cognitive map (Sánchez and Lumbreras, 2000). In the real space, most of the participants (70%-100%) were able to transfer and apply spatial information that was acquired during their VE exploration (Evett et al., 2009; Lahav et al., 2011).

4. CONCLUSIONS

In the past 15 years, 21 VEs have been researched and developed for the use of people who are blind. Each research group designed and developed a unique solution for O&M preplanning systems to help people who are blind gather new spatial information or to act as an O&M rehabilitation simulator.

The encouraging research results have important implications for the continuation of the research and development. Hopefully, these promising results will have important influence on future research and development, focusing on O&M skills and cognitive spatial behavior in the VE. From the implementation side, the use of affordable VEs as an O&M aid can lead to direct influence on users' quality of daily life, including professional education, employment, social life, and rehabilitation of people who are newly blind. We hope that this paper will expand the awareness of the use of the VE as an O&M aid by research and development groups, users, rehabilitation services, and other public service providers. Unfortunately, today, despite the encouraging results, these VEs are not available outside research labs.

The research results showed that some of the VEs ask the user to operate several devices at the same time, which can affect the user's ability to work independently or affect his or her cognitive load in gathering and analyzing extensive information. Future applications will need to maintain a balance between user-friendly systems and audio and haptic representations.

Further research is needed to continue the research of Simonnet et al. (2010), to examine if and how the VE's spatial exploration methods, allocentric or geocentric representations, influence the user's spatial model. This is a topic that was less commonly examined and which might have an influence on the user's ultimate ability and outcome in using a VE. Additionally, the research must proceed to examine the real-life scenarios in which this type of O&M aid is most needed, such as outdoor and complex spaces.

In the mean time, handheld device technologies are increasingly being used by people who are blind. Until three years ago, users who are blind carried a variety of devices, including cell phone, GPS, note taker, color identifier, drug labels reader, and music or audio book device. Today one handheld device offers all of these technologies and more. Two years ago, Google announced a new Android application called Intersection Explorer (Google Co., 2010), a preplanning application that allows people who are blind to explore the layout of streets on Google Maps by using touch to move along the street and to receive auditory directions. Tactile handheld devices have been developed (Fukushima and Kajimoto, 2011; Youngseong and

Eunsol, 2010), which allow users who are blind to gather tactile feedback on the backside of the handheld device. Encouraged by research results, we suggest integrating an O&M aid application based on multimodal interfaces in a handheld device. The handheld device's screen will fit the user's palm, enabling collection of all the tactile information. This unique application will allow users to explore the spatial space in advance, preplan a new path, install landmarks, apply these landmarks through the GPS in the real space, share this information with multiple users, and use different spatial layers through the GPS (such as user's landmarks, public transportation, and road construction). These and other new technologies hold important potential to improve the quality of life of people who are blind.

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Development of a visual impairment simulator using the Microsoft XNA Framework

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ABSTRACT

This paper describes the development of a visual impairment simulator based upon a virtual environment developed using Microsoft's XNA framework and High Level Shader Language. Shaders were developed to simulate the effects of cataracts, macular degeneration, glaucoma, myopia and hyperopia. These were then used to impair the real time display of an explorable 3D virtual environment. The simulator was evaluated by a qualified optician and trialled with a group of students. The paper concludes that further development is required to fully and accurately represent the impairments, however the simulator remains effective in improving participants level of understanding of visual impairments.

1. INTRODUCTION

There are around 2 million people in the UK who have a significant visual impairment. Due to a lack of familiarity with the symptoms and a lack of awareness of the dangers an additional 1.9 million people with diabetes and 250,000 people with early-stage glaucoma also have a high risk of needlessly losing their sight. Furthermore, understanding how visually impaired people see the world is also extremely useful for people who need to assist them, or those who design the environments around which they are expected to move. Finding effective methods to increase awareness of the symptoms of eye diseases and to demonstrate the difficulties faced by visually impaired people is therefore an important and challenging task.

Historically the simulation of visual impairments has mostly been achieved through the use of 'artist impressions'. Photographs which have been modified to recreate an impression of visual impairments remain widely used as the standard training tool for medical professionals. More recent approaches have utilised physical interventions to modify vision, for example Fine and Rubin's (1999) use of frosted acetate to simulate the effect of cataracts. This method has been extended to a range of visual impairments utilising customised lenses. These can be seen in SimSpecs, a set of special glasses designed to represent a variety of impairments (Aballea & Tsuchiya 2006). SimSpecs offer many significant benefits, they are simple to utilise and cheap to implement. Unfortunately there is an inherent danger associated with moving around a physical space with impaired vision, limiting the range of activities which can be attempted while wearing the spectacles.

Computer technology has been employed to create simulations of impaired vision. Software tools have been developed which enable designers to view 2D images modified according to the degree and nature of an individuals colour deficiency (Walraven & Alferdinck 1997), as well as simulating the effects of myopia, macular degeneration, cataract, glaucoma and retinopathy (Hogervorst & van Damme 2006), (Goodman-Deane et al 2007), (Banks & McCrindle 2008).

There have been several notable attempts to simulate visual impairments within the context of a VR virtual environment. Jin et al. (2005) developed an immersive virtual tour of an apartment. This desktop application simulated age-related macular degeneration, glaucoma, protanopia and diabetic retinopathy. The simulator was “designed for patient education, health care practitioner training, and eye care specialist education”. Maxhall et al. (2004) developed a simulator, again based upon an apartment which was designed to emulate visual anomalies which may occur following a stroke. The visual representation of these anomalies included motion blur, camera movement (to simulate dizziness & nausea) and hiding objects on the left and side of the view (to simulate unilateral neglect). The apartment was viewed through a head mounted display; movement was via an adapted wheelchair and interaction facilitated through pinch gloves.

Despite having a graphical fidelity which was far removed from what many would regard as 'realistic', and offering only a limited scope for the user to truly explore or interact with the environment these studies highlighted the potential of this kind of simulation. Jin et al. (2005) concluded that the application developed can "...be used for the education of patients and the training of ophthalmologists". It continues to say that experiencing a first-person view of visual impairments "...can be used to teach medical professionals to recognise the kinds of problems that their patients may be experiencing". Maxhall et al. (2004) found that their simulator was "usable for training caregiver's empathy for stroke patients, possibly creating an increased understanding for stroke patients daily problems".

Previous work by the lead author (Lewis et al. 2011) developed a simulator by implementing a game mod based on the *Unreal Tournament 3* (Epic 2007) game. Visual impairments were applied to a virtual environment of a refectory using the graphics post processing chain available within the game editor. In this implementation the impairments are more representative than realistic. There is no simple way of modifying them on the fly to be able to represent a range of impairments and the authors do not consider the representation of the impairments to be an accurate simulation of impaired vision. Despite this the results of testing were very encouraging. Opticians who reviewed the software rated the effect as highly realistic, a visual impairment awareness advisor confirmed the utility of the application as an educational tool, and effectiveness testing appears to show a substantial increase in the test subjects level of awareness of visual impairment. This was surprising, considering the short period of time that the test subjects utilised the simulator, and the limited accuracy of the impairments themselves.

2. OBJECTIVES

The aim was to develop a simulation tool suitable for use in situations where an accurate representation of an individual's vision might be necessary. This might be as an educational tool in a optometric, ophthalmologic or nursing training to highlight the range of impaired vision that a particular problem can cause, or, for example as a better method for an optometrist to explain a child's visual impairment to family members. It was hoped that a configurable simulation would offer flexibility in representing the range, as well as the the nature of visual impairments and enable them to be more effectively understood and accounted for. In this context the authors were also interested in whether the substantial increase in reported understanding, noted by Lewis et al. (2011), would be replicated.

To achieve this required a programmable rendering system. High Level Shader Language (HLSL) is a proprietary language developed by Microsoft which operates in conjunction with the Direct3D API. It offers a great deal of flexibility in this context, able to leverage the full capabilities of modern graphics cards and allowing access to the full range of visual effects seen in AAA computer games. Additionally using HLSL enables the same shader algorithms to be utilised in a wide range of development and simulation environments. Specifically in this case the development also sought to establish whether the Microsoft XNA framework was a suitable development platform for a simulation of this type, what drawbacks using this framework may impose, and investigate the limitations of rendering computationally expensive shader algorithms in real time on standard PC hardware.

3. DEVELOPMENT METHODS

A visual impairment simulator, based upon an office environment was created using the Microsoft XNA framework and Blender for modelling and 3D scene creation. High level shader language (HLSL) was used to simulate the visual impairments as post process effects. Simulations of myopia, hyperopia, cataract, macular degeneration & glaucoma were developed, and an interface devised to enable these impairments to be combined and adjusted for severity in real time using a set of sliders.

3.1 Shader Methods

Several key components were identified that would be required for use by the impairment shaders. The four main identified components were a blurring technique, colour tinting filter, partial screen overlay and a distortion effect.

3.1.1 Blurring Technique. Blurring techniques can often pose a challenge for development in a shader language as they sample a large number of neighbouring pixels then take an average with some weighting function to determine the result of the blur. This poses a problem for shader languages as the number of pixel samples they are able to utilise without impacting performance is limited. An efficient and effective blurring method which could be utilised within these constraints is a Gaussian blur. Whilst this is not strictly speaking an optically correct way of representing out of focus vision, the subtle difference is unlikely to be noticed.

3.1.2 Colour Tinting. A colour tinting filter is required to simulate the yellowing of the lens due to cataracts. A first simple stage is to create a monochrome representation of the source image with the desired colour. First the luminosity of the source image must be determined. As the human eye is not equally sensitive to the red, green and blur primaries a common method to create a greyscale closer to one perceived by a human eye is to use the equation below. This creates a greyscale according to wavelength function.

Luminosity = (Red * 0.2989) + (Green * 0.5870) + (Blue * 0.1140)

After the fully tinted image is created, the amount of tinting can be controlled by using different amount of the tinted and original image.

Tint image = Tint colour * Luminosity

Composite = (Tint amount * Tint image) + ((1 – Tint amount) * Source image)

3.1.3 Partial Screen Overlay. Several impairments require that an area of vision becomes obstructed. In the previous simulation (Lewis et al. 2011) a black image with an alpha channel was used for transparency. This implementation extended that approach by making the shape more irregular and enabling the alpha value to be modified in real time. Alpha values stored are between zero and one. Values at one are completely opaque. Figure 1 demonstrates a sample alpha map used for the macular degeneration overlay.

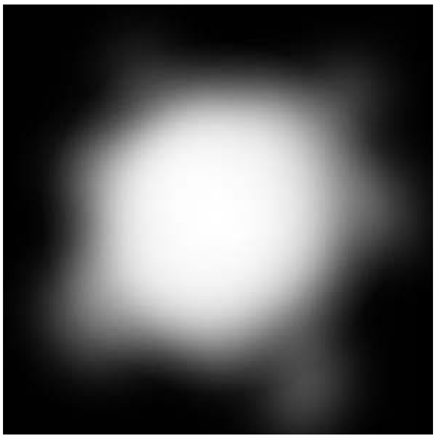

Figure 1. *Macular degeneration overlay alpha map.*

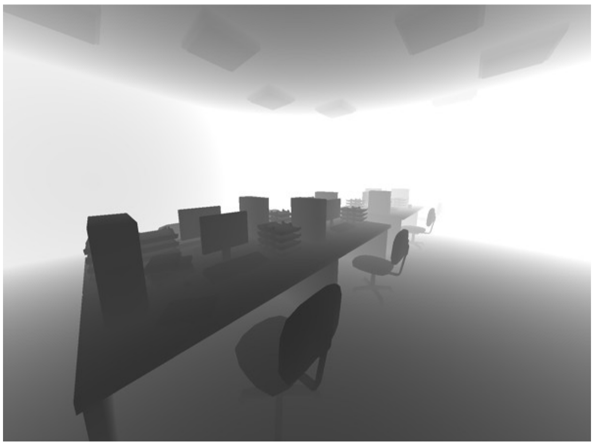

Figure 2. *Generated depth map.*

To allow the adjustment overlay to adjust how severe the impairment appears the alpha values can be manipulated to change the level of visibility of the overlay. Subtracting values from the alpha map will make the image appear less opaque.

Adjusted alpha = Source alpha – (1 – Impairment severity coefficient)

Any alpha value in the overlay lower than the impairment severity coefficient will have no effect, as the images becomes darker the obstruction expands from the centre, it will first appear as a small dot in the centre of the vision, then grow outwards as the severity level is increased.

3.1.4 Distortion Effect. Screen space distortion effects are commonly used in games to recreate effects like heat waves and refraction in transparent materials. It is a simple process where a source image is taken then resampled, offsetting the value of some pixels to add twists and distortions to the image. Changing the pattern of resampling offsets can vary the effect. To allow the effect to be changed without requiring significant recoding, a shader was constructed to use an image to represent the direction and magnitude of each offset. This allowed the effect to be customised by simply adjusting the image. The offset works in screen space, so sampling offsets can be represented as a two dimensional vector. Another shader technique known as normal mapping stores vectors in texture space using separate channels on the image to represent each component of the vector. As a single texture channel can only store values between zero and one this value is modified to change it into a range between minus one and positive one.

Offset axis i = (Offset texture channel i * 2) – 1

By using two channels in an image to store the offset for each dimension of the vector a unique offset is stored for each image pixel. As a final step the offset image is made smaller than the screen size, so when the offset image is sampled the offsets stored in each pixel are smoothly interpolated. This gives a wavy effect rather than very sharp and sudden offsets. To control the severity of the offset, after the offset vector is calculated it is simply multiplied by the severity amount to increase or decrease the magnitude of the offset.

3.1.5 Depth Based Impairments. Depth of field blurring in games is a particularly difficult feature to implement without causing a significant and negative hit on performance. Although a working implementation of blurring has already been discussed, a method of extracting the depth of each pixel was required in order to modify the degree of blurring based upon focal distance. The traditional graphics pipeline uses vectors to store the position of vertices in three dimensional space, and matrices to transform these vectors into a screen space. Taking advantage of the fact that at the stage before perspective is applied every position vector's magnitude is equivalent to its distance from the camera (as the camera is at the origin). The position of this vector can be passed down into the pixel shader. This makes it possible to interpolate between the three vectors making up each triangle to give the position of each pixel relative to the camera. From this the magnitude of the vector can be calculated giving the distance from the camera.

As this returns the depth in world units (in this case one world unit is equates to one metre) the results are converted to a range between zero and one to be written to a texture. To accomplish this, the total distance is divided by eight. This limits the range of distances from zero to eight metres. Any values beyond one (eight metres) are limited to one when the depths are drawn to the depth texture.

3.2 Simulation of the Impairments

These component effects were combined to recreate the appearance of a series of visual impairments as detailed below

3.2.1 Cataracts. A Gaussian blur filter was used to allow control over the patient's loss of visual acuity as light scatters when passing through the lens of the eye. A colour tint filter was also utilised, allowing the control of how yellow and washed out the vision will become. Additionally an overlay of a white cloudy image is used to show the gradual increase in lens cloudiness. The overlay is designed such that the overlay will never be completely opaque even at full severity, leaving the impression of looking though a fog.

Figure 3. *Implementation of cataracts simulation.*

3.2.2 Macular Degeneration. An image overlay was used to simulate the loss of central vision. It was created to allow the loss of vision to occur initially in the very centre of the vision and spread outwards as the severity level is increased. A Gaussian blur was used to show the loss of visual acuity. A distortion shader was used to simulate the effects where straight lines appear wavy to the patient. The higher the impairment severity the stronger the offset values making the line less straight the more severe the condition.

3.2.3 Glaucoma. An image overlay was used to simulate the loss of peripheral vision. A Gaussian blur was also applied to demonstrate the loss of visual acuity that frequently accompanies the impairment.

3.2.4 Myopia/Hyperopia. Barsky et al. (2002) implemented a vision realistic approach by rendering out burred images of the final scene then interpolating between them to get the correct level of blur in the composite image. This method was adapted to work in real time using a quick Gaussian blur to create a blurred image of the scene, using the depth information stored for each pixel to determine the level of focus, then interpolating between the scene and blurred image to make the correct areas appear out of focus.

Blur amount = pixel depth * severity coefficient

Colour = (Source image * Blur amount) + ((1 – Blur amount) * Blurred image)

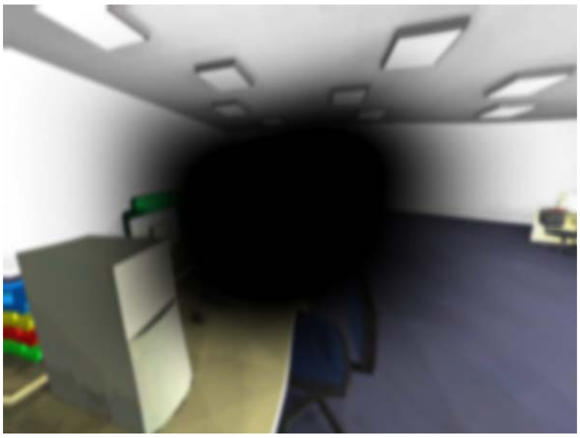

Figure 4. *Implementation of macular degeneration.*

Figure 5. *Implementation of glaucoma.*

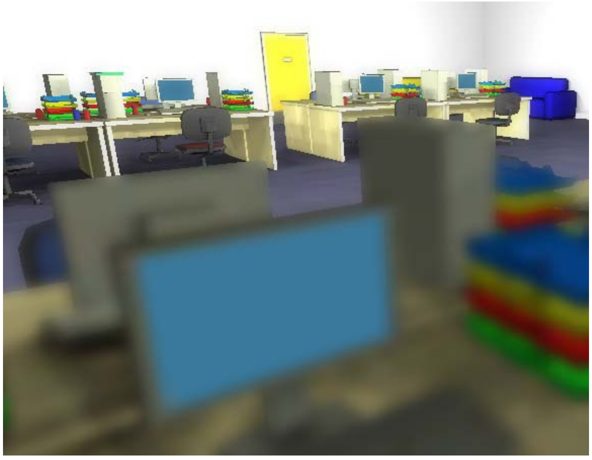

Figure 6. *Implementation of hyperopia.*

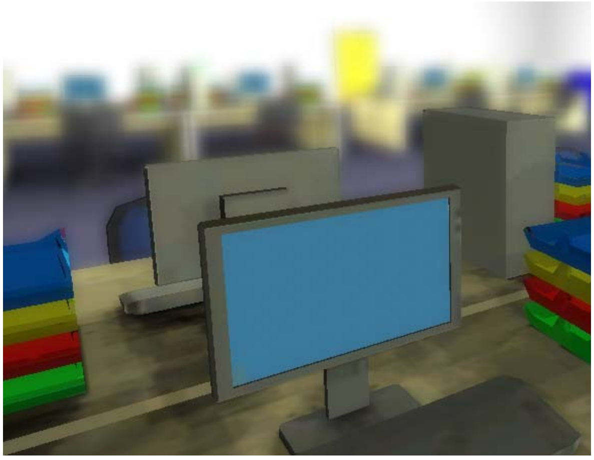

Figure 7. *Implementation of myopia.*

4. TESTING

A two stage testing method was employed. The first phase was aimed at validating the accuracy of the tool. To achieve this a qualified optician was consulted to confirm the accuracy of the impairments, and the potential utility of such a tool in her own professional practice. To test the effectiveness of the simulator for training and education purposes a second phase of testing was undertaken. This was based on a sample group of 23 people, university students of mixed gender aged between 20 and 25 years old.

4.1 Validation Testing

The optician was shown how to operate the simulator, and then allowed to experiment with moving around the environment and adjusting the impairments with assistance to facilitate where required. Qualitative feedback was gathered through dialogue throughout the process, and through conversation afterwards.

4.1.1 Cataracts. The optician identified that the cataracts simulation did not give a good representation of the variability of cataracts. Additionally comments were made on the level of severity offered by the simulator.

> *"When I turn the settings right up it gets to around the point where a patient may be referred. A patient needs 6/12 vision to get a referral in Lincolnshire."*

From this it is clear that at this stage the simulation is not capable of recreating the full range of cataracts in type or severity. The level of severity is however sufficient to simulate up to the point where a patient would require surgical treatment.

4.1.2 Glaucoma. The simulation of glaucoma was described as generally accurate, two suggestions were made to increase the fidelity of the simulation.

> *"There is a gradient between the parts that are normal and have no vision, I would expect the change to be much more sudden."*

"*When I turn the effect right up I can still see quite a large area in the middle of the screen, I would expect this to be a much smaller area.*"

Although this highlights that the simulation does have some significant flaws in the representation, the changes required are not problematic to implement.

4.1.3 Macular Degeneration. Macular degeneration was identified as the impairment that required the most significant changes to improve accuracy.

"The blind area does not grey in gradually, smaller blackened areas would appear during the initial stages. These would grow larger as the condition progresses."

"*Blurring and waviness would only happens the centre of the vision, the peripheral vision is not effected.*"

"*The angle of effect is much smaller, around 7 degrees.*"

"*I can just look to the side of the blind spot.*"

These points illustrate a limitation present in all investigated visual simulations. In order to very accurately simulate the impairment it is necessary to align it with the foveal area of vision. As this area is extremely mobile any solution will require the use of eyetracking. The associated latency of this, combined with the graphical complexity of the shaders may prove to be pushing the boundaries of what is possible on current hardware. Modifying the display in real time depending upon where the user is looking however remains a highly desirable goal.

4.1.4 Myopia & Hyperopia. When the severest settings were simulated it was noted that the effects were insufficiently pronounced with little blurring within a metre.

"The symptoms are very mild, the far point of clear vision is much longer than I would expect. I have myopia and unless I hold something up here (within close proximity to the face) it appears out of focus."

"The slider doesn't make much sense, it would be nicer to have the effect measured in dioptres."

This point is understandable from an optician's point of view as these are the terms opticians are used to working with. It does however highlight the question of how an adjustment of this type should be labelled for a more general audience, and to what level of severity the simulation should extend.

4.1.5 General Evaluation of Simulation. The opticians review provided some evidence in support of the hypothesis that increasing the amount of interactivity in a visual impairment simulator is an important factor in representing the impact of visual impairments.

"*Moving around and seeing things come in and out of focus really highlights how your world is really in the first meter of your vision. We tried something similar with our website on images but interacting gives a better sense of having the impairment.*"

In addition to the large number of suggestions for improvement the optician did give a very positive reaction to the simulation.

"It would be of huge help when trying to explain the effects of impairments to patients."

"Organisations like the RNIB are desperate for methods to inform the public about visual impairments and a program like this could really help this."

By following the suggestions and increasing the accuracy and usability of the simulation it seems that this tool could have serious potential for a real world application. The results highlight the utility of having an experienced vision specialist involved during the development process, as following an iterative development of refining the impairments based upon expert feedback will eventually lead to more accurate and nuanced implementations of impairments than a standardised 'textbook' image.

4.2 Effectiveness Testing

The effectiveness testing on students utilised questionnaires to establish the participants level of awareness about visual impairments. Part one was taken before use of the simulation; the participants were asked to describe their knowledge of visual impairments in general and then questioned about specific impairments. Participants were then given a short demonstration of how to use the simulator tool and allowed to utilise the simulator for as long as they wanted. When they had finished with the simulator they were asked to complete

the second questionnaire. This asked a similar set of questions designed to show any change in awareness after using the simulator.

The first statement put to the participants was “I already have detailed understanding of visual impairments and how they affect the lives of the visually impaired.” No participants “strongly agreed” with the statement, three participants “agreed” and three were “undecided”. Fifteen “disagreed” and two “strongly disagreed” . These results could be interpreted as suggesting that the participants generally have an awareness of visual impairments but without detailed knowledge.

After using the simulator the following statement was put to the participants “Using the visual impairment simulator has improved my understanding of visual impairments in general and how they affect the lives of the visually impaired.” The responses to this question indicate a clear shift towards reporting a greater level of understanding, With seventeen participants saying they “strongly agree” with the statement and the remaining six saying they “agree” it suggests that the simulation was very successful at increasing understanding of visual impairments with every participant believing the simulation offered an improvement on their existing knowledge. As the survey does not actually test user knowledge, only asking for the user’s opinion the results must be used with caution, however it shows a very strong indication that the simulator does improve people’s understanding of visual impairment.

“I am familiar with the effects of ’impairment’ on the visual system”

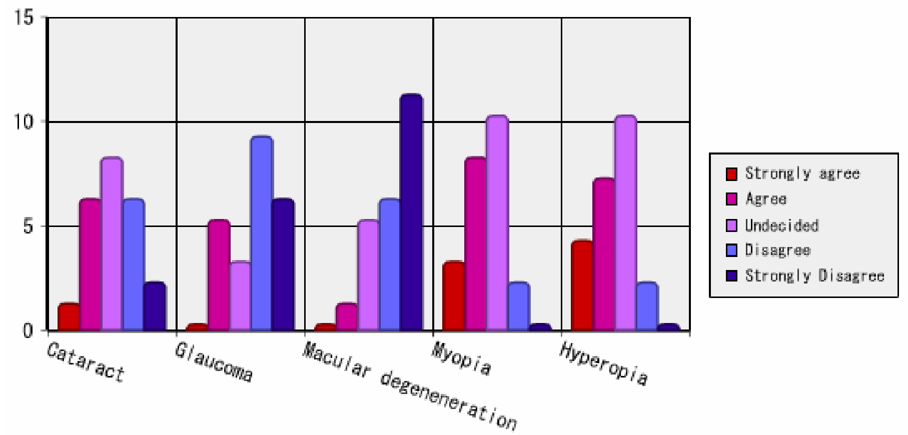

Figure 8. *Understanding of impairments before using the simulator.*

Figure 8 shows the participants understanding of visual impairments before using the simulator. As the data shows, people's base level of understanding about visual impairments is quite variable. Myopia and Hyperopia however tend to have a good proportion of participants who believe they have a good understanding of these impairments. A probable reason for this is that long and short sightedness are simply more well known, and the common names offer a clue as to the nature of the impairment.

“After using the simulator I am now familiar with the effects of 'impairment'”

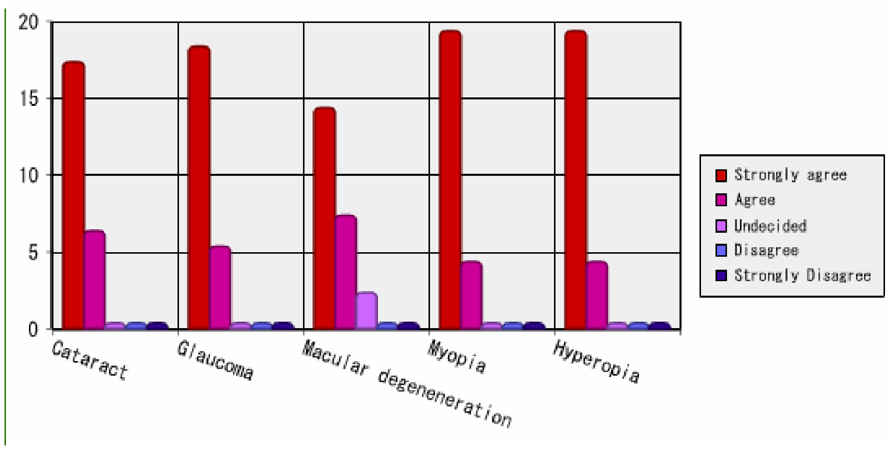

Figure 9. *Understanding of impairments after using the simulation.*

After using the simulation most participants believe they are familiar with the effects of all of the impairments, with the majority strongly believing. Of course, these results were gathered immediately after the use of the simulation when the experience is very fresh in the participant's minds so the results should be viewed with some caution. They do however show a very strong indication that the subjects believe that the simulator has improved their understanding of visual impairments.

To test the simulations interactivity the participants were asked if "Allowing movements around the environment provided a better sense of the impairments than looking at a still image." Eighteen of the participants strongly agreed with this statement and the remaining five agreed. This response shows a strong indication that interactivity is a valuable factor when trying to simulate visual impairments. It is worth noting that a significant number of the test participants were known to enjoy playing computer games. This may bias them towards a preference for interactivity; additionally their familiarity with the controls required for navigating 3D environments mean that these participants found this method of interaction familiar and natural, where others may find navigation to be much more of a usability issue.

5. CONCLUSIONS AND FUTURE WORK

The results of the effectiveness testing show a strong indication that the users had gained a good understanding of visual impairments though using the simulation tool. Seventeen users strongly agreed, and the other six agreed with the statement that "Using the visual impairment simulator has improved my understanding of visual impairments in general and how they affect the lives of the visually impaired". Eighteen users strongly agreed and five agreed that "Allowing movements around the environment provided a better sense of the impairments than looking at a still image".

From the qualitative results gained it appears that the severity customization was fairly successful in its implementation, however the range that could be simulated was found to be too limited, with the highest settings not restricting vision enough to accurately replicate a severe impairment. Overall the simulation accuracy appears to be good enough for the application. Further work will be to implement more detailed and computationally expensive simulations, and investigate if an increase in simulation accuracy actually offers significant advantages over the lower end simulation. This is an important consideration as increasing the computational power required to run the system decreases the availability of the hardware needed.

High Level Shader Language was confirmed to have sufficient flexibility and computational efficiency to offer a great platform for the improvement and refinement of the shader algorithms. As the HLSL shader code is not specific to any particular application, it can potentially be integrated into a variety of applications . For example integration into CAD packages will allow architects or interior designers to understand how their spaces would be seen by a visual impaired individual. XNA was found to interface easily with the shader code, and allowed the rapid prototyping of a simple environment. Future work in this system will sidestep the difficulties of creating and lighting a virtual environment using XNA, and instead focus upon using the shader algorithms to create an augmented reality approach using live video.

To further develop an interactive environment, research is currently underway using existing game engine solutions like the Unreal Developer Kit to manage the world creation and interactivity features needed. These systems have much more advanced rendering pipelines than has been implemented by the current simulation and are already set up for complex interactivity. This would allow a much higher quality of rendering, increasing the immersion of the simulation by providing a more realistic environment, with interactive tasks to complete.

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Chilean higher education entrance examination for learners who are blind

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ABSTRACT

In the context of the admissions process for Chilean state universities, there is a knowledge-measuring instrument called the University Selection Test (PSU, for its Spanish acronym). This instrument of evaluation is designed to measure the level of knowledge in various learning sub-sectors such as Language and Communication, Mathematics, History and Social Sciences, and finally Science. For each learning sub-sector, students use a paper facsimile with questions that each have 5 possible answer choices, which are recorded on a separate answer sheet. Based on a contextual analysis of the problems that people who are blind have with participating in the regular admissions process for Chilean universities, the purpose of this study was to design, implement and evaluate a digital pilot system that adapts the Chilean university entrance system, PSU, in the area of Language in Communication for people with disabilities based on audio and haptics. This pilot allowed for the inclusive, equitable and autonomous participation of people with visual disabilities in the university admissions processes. The results demonstrate the creation of a system called AudioPSU, which provides the necessary autonomy and respects the working time that each user needs to respond to the questions in the PSU. In addition, the system is shown to help users to map the structure of the PSU facsimile for Language and Communication. Finally, initial results show that AudioPSU allows for the integration of people with visual disabilities in the admissions process for Chilean universities.

1. INTRODUCTION

According to the WHO, there are approximately 314 million people in the world with visual impairments, of which 45 million are blind. The geographic distribution of this impairment is not uniformly distributed throughout the world, and approximately 85% of people with visual impairments live in developing countries (WHO, 2011).

In Chile, the results of the CASEN 2009 survey indicate that 7.6% of the population has at least some degree of disability, in which the most frequent disability (32.7%) corresponds to blindness or visual difficulties, even when using glasses (Ministry of Social Development, 2009).

Education in Chile is a sensitive issue for people with disabilities, for which reason their integration must take place as soon as possible. The ENDISIC 2004 survey showed that while 27.5% of the general population is currently studying, among the disabled population this shrinks to only 8.5% (Senadis, 2004).

In order to implement educational integration in Chile, the School Integration Project (PIE, for its Spanish acronym) emerged. PIE is a school system strategy with the objective of contributing to the continuous improvement of the quality of education provided in the school system, favoring presence in the classroom, participation and the learning of expected lessons for all students, and especially those with special educational needs, be they of a permanent or temporary nature (Mineduc, 2012).

On the other hand, regarding the admissions process to Chilean universities, managed by the Council of Rectors, there is a knowledge-measuring instrument called the University Selection Test (PSU, for its Spanish acronym). This instrument of evaluation is designed to measure the level of knowledge in various

learning sub-sectors such as Language and Communication, Mathematics, History and Social Science, and finally Science. The procedure for using this instrument functions traditionally with paper and pencil, in which students use a paper facsimile in order to read each of the questions (which include 5 possible answer choices), and once they decide on the correct answer they mark it on a separate answer sheet.

In this context, people who are blind do not have the necessary autonomy to take these tests. Currently in Chile only people with moderate visual impairment can take visual tests, using special aides and adequate lighting, almost like any other person who does not have any visual disability. For this reason, these individuals can be integrated into the knowledge-measuring process by taking the PSU, through a "special process" (isolated) for taking the tests, as they possess enough residual vision to be able to see the graphic elements contained in the test. During this special process they have the aide of two assistants; one in charge of recording what the person wants to answer, and another in charge of verifying that the first assistant adequately records what the visually impaired person has indicated. Furthermore, they are provided with additional time in order to respond to each test (Mineduc, 2011).

The previously presented needs and failures became the basis for public policy aimed at integrating visually impaired citizens into the PSU test-taking system, marking a landmark policy in Chile.

There is evidence of similar initiatives from other countries (China, 2002; Higher Education in India, 2011; Kaczmirek & Wolff, 2007; Katoh, 2002). Kaczmirez & Wolff (2007) presented guidelines for the design of self-administered surveys for visually impaired and people who are blind within a mixed mode approach (paper-based, Braille-based, Web-based). Katoh (2002) researched the use of tactile graphics in the entrance exams for Japanese universities, obtaining the result that learners who are blind are able to take tests with tactile graphics, but require more time to answer the questions than people with normal vision. Another possibility to balance this aspect is to eliminate the questions with graphics, as is done in the Swedish Scholastic Aptitude Test (Katoh, 2002). In India, special science exams in physics, chemistry, biology and mathematics were announced for 2012 and 2013. These tests will be adapted for students with visual impairments by excluding visual elements such as diagrams or graphics. In China in 2002, the possibility was opened for students to be integrated into the regular process for the national university entrance examination (China, 2002).

The purpose of this study was to design, implement and evaluate a digital pilot system that adapts the Chilean university entrance system, PSU, in the area of Language in Communication for people with disabilities based on audio and haptics.

2. AUDIOPSU SYSTEM

Based on the analysis performed by a multidisciplinary team of professionals involved in this work, in which special education teachers specializing in visual impairment participated together with computer engineers, the following baselines for the design of a system that contributes to improving the conditions in which people who are blind currently participate in the PSU were established:

- *Do not require special spaces to take the tests.* People with visual impairments must have the chance to take the knowledge evaluation tests in the same rooms as the rest of the people participating in the process.
- *Have an equivalent measuring instrument.* People with visual impairment must have the chance to utilize a knowledge-measuring instrument that is equivalent to the PSU that is currently used by sighted people. This can be achieved through an adapted computational system.
- *Does not require assistants.* People with visual impairments must have the chance to take the tests autonomously, just as the rest of the test-taking population. This can be made possible through the use of audio feedback for reading the questions, and the use of a haptic interface to answer the questions.
- *Having the advantages that sighted people have in order to navigate throughout the questions.* People with visual impairments must have the chance to make decisions on how to answer the questions, choosing the order in which they do so and thus have the freedom to optimize the time that has been assigned for them to finish the test.

In following these baselines for the design, a hardware and software solution was created called AudioPSU, reusing a longitudinal research work on audio for cognition in users who are blind leaded by the research group for more than twenty years (Sánchez, 2008). The application seeks to allow people with visual impairments to be able to participate in the Chilean University Selection Process in an improved and more inclusive way. This eliminates the need for an assisted PSU in which the user does not have the tools needed

to execute actions autonomously, and which was carried out in the context of a process lacking the normal conditions in which the university selection test is normally taken.

In order to design the software, the logic needed to structure the way in which learners review and respond to test questions, which is similar to the structuring of the sections included in the PSU, was integrated. This was made in order to provide more equal conditions for the measuring instrument used to determine entry into state universities. The solution integrates Text-to-Speech (TTS) to read the questions, and ad-hoc hardware to be used as an entry interface for people with visual impairments, in order to be able to navigate through and respond to the questions.

2.1 Software

The software consists of an adaptation to the Language and Communication PSU, which structurally possesses 3 different sections: I) Knowledge of basic concepts and general language and communications skills, II) Text production indicators, III) Reading comprehension.

There are 4 kinds of questions with varying specific forms included in the PSU Language and Communication test. Section I groups questions of the same kind. Section II has 2 sub-sections: A) Managing connectors and B) Writing plan, in which each sub-section groups a certain kind of question different from the other sections. Finally, section III is subdivided into various groups of questions, in which each group includes a common text made up of various paragraphs, which serves to resolve and answer reading comprehension questions for each group.

An Index of questions was implemented within the software, following the original test structure and thus allowing for a faster question review process. One of the navigational advantages that sighted people have on the paper test is the speed with which they can find the titles of the various sections of the test. To emulate this way of interacting and to reflect the desired level of navigation, it was decided to use navigation by sections for the entire test, in addition to a mode of navigation by questions in Section I, navigation by sub-sections and questions in Section II, and navigation by groups and questions in Section III. This allows the user to change quickly from one section to another, as well as between sub-sections in Section II and groups in Section III. It also included the option to go directly to a specific question on the test, granting the same degree of navigational freedom as sighted people.

Regarding the presentation of the questions, each question indicates its number and section or sub-section. At any time learners can ask for instructions, return to the index, go to the previous question, go to the next question, save the selected answer choice, or erase their previous answer choice.

For the questions in Section I, the learner is presented with the question and then the answer choices. In some cases, the question contains additional information, which is previously presented to the user, and he or she can access this information as often as needed.

For the questions in sub-section A from Section II, the user is presented with the sentence to complete, leaving a considerable pause in the audio where the connectors should go. In this way, the user can clearly identify where the connectors that must complete the sentence are to go. Finally, the user is presented with the answer choices, in which each of them presents the complete sentence with a series of different possible connectors.

For the questions from sub-section B from Section II, the user is presented with the title of the text to be completed, and then with the various sentences that could be used to complete the sentence preceded by an identifying number. The user can explore these sentences one by one as many times as necessary. Finally, the answer choices are presented, in which each one presents the order in which the sentences should go through their identifying number.

For the questions in each group from Section III, first the common text is presented, structured into paragraphs in such a way so that the user can read each paragraph independently. Then the questions are presented along with the pre-answer choices for each question (if necessary). The pre-answer choices consist of numbered sentences in which the user must select which are true. The user can access each one independently. Finally, the answer choices are presented. In the case that there are pre-answer choices, each answer choice is made up of a list of numbers corresponding to the pre-answer choices.

In some cases, words are highlighted in the questions, in that they are visually underlined. In order to highlight these words, quotations marks and capital letters are used, making the TTS announce the quotations and read these words with a higher degree of emphasis.

2.2 Hardware

The working environment for AudioPSU (see Fig. 1) is made up of the following hardware devices: (i) Netbook, preloaded with the software that controls the system and the data that makes up the PSU test facsimile for Language and Communication (see Fig. 1A); (ii) Numpad as the entry interface for navigation of the facsimile and for writing the test answers (see Fig. 1B); and (iii) Stereo headphones as the output interface, used by the system to provide the user with the questions and instructions through a synthesized voice (see Fig. 1C). A Braille symbol was incorporated into each key of the numpad, corresponding to an action within the system that users can easily identify (see Fig. 2).

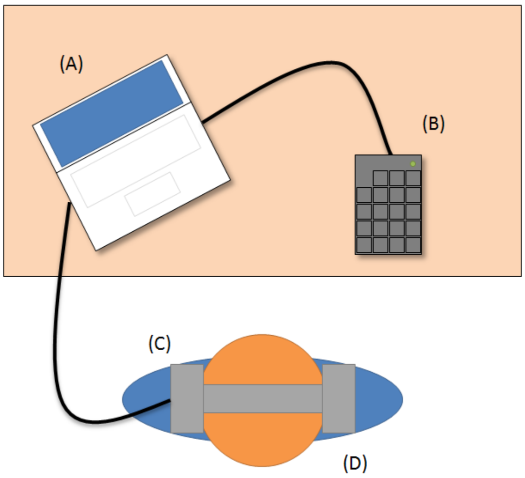

Figure 1. *Work station for the AudioPSU user, (A) Netbook, (B) Braille Numpad, (C) Stereo Headphones, (D) User Who is Blind.*

The functions of the keys for executing the system were the following:

- *"/" key.* Allows for listening to the instructions corresponding to each section of the test.
- *"*" key.* Allows for going to the index of the section and asking where the user is located within the test.
- *"-" key.* Allows for going to the beginning of the index.
- *"8" key.* Allows for going from question to section, from sub-section to section, from group to section, from question to sub-section, and finally from question to group.
- *"4" key.* Allows for moving to the left between each section, sub-section, group and the questions.
- *"5" key.* Allows the user to choose entering into a question, section or sub-section.
- *"6" key.* Allows for moving to the right between each section, sub-section, group and the questions.
- *"2" key.* Allows for going from question to section, or from sub-section to question and from group to question.
- *"+" key.* Opens a window where the user can write a question number using the numeric keys and then press the "+" key again, and the system loads the corresponding question.
- *"Back Space" key.* Allows for erasing the number of the question in the selection window that is loaded after pressing the "+" key.
- *"0" key.* Allows for starting and pausing the text that the system is reproducing.
- *"." key.* Allows for listening to the information regarding where the user is located within the test.

2.3 Interaction

The interaction with AudioPSU (see Fig. 3) starts with the user with visual impairment (see Fig. 3A) who, thanks to the numpad, can navigate (see Fig. 3B) between the various interfaces provided by the software (see Fig. 3C). The "Index" interface allows the user to select a particular question and see if it has been answered or not, and the structure of the "Question" interface allows the user to identify elements of the question such as the question phrase, complementary texts and the answer choices (see Fig. 3C). Finally, the system provides information regarding navigation through the text in order to resolve the questions through TTS, which can be heard through stereo headphones (see Fig. 3D).

Figure 2. *Numpad with Braille markings.*

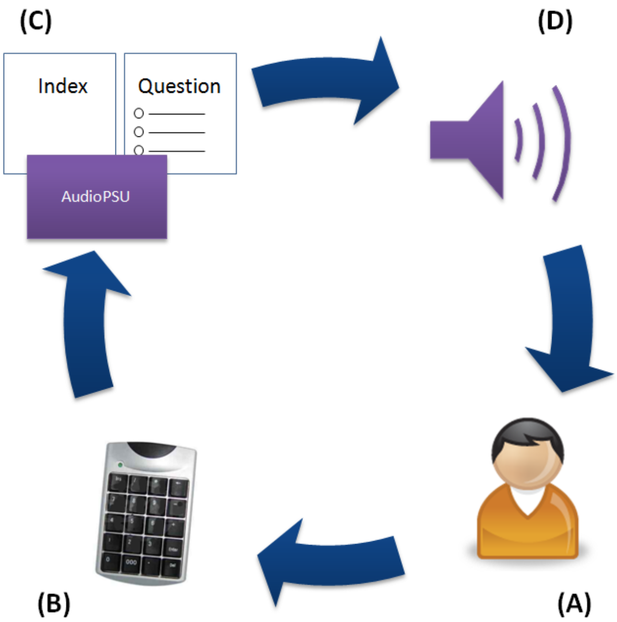

Figure 3. *The User's Interaction with AudioPSU*

3. EVALUATION

During the development of the accessibility solution for taking the PSU in Language and Communication (AudioPSU), various institutions that work on the education and rehabilitation of visually impaired people were contacted. These included the National Union of Institutions for the Blind of Chile, the Santa Lucia Educational Center, the Hellen Keller School, and students within the University of Chile (Law School) and the Metropolitan University of Educational Sciences (Special Education School). These institutions were chosen in order to work with users who could help us to improve the design of the prototype.

This allowed for the selection of an adequate synthesized voice (tone and speed) for the reproduction of the texts. It was also possible to test the proposed navigation with the numpad and to identify if the distribution of the content facilitated total or partial comprehension of the test.

In this way, it was possible to generate changes in the software design beforehand, adjusting it to the needs of users with visually impairments, attending mainly to the suggestions that were provided collectively with the aim of implementing effective solutions from a variety of potential users of the system.

3.1 Sample

The sample was made up of a total of 7 people with visual impairment. Of these people, 3 were women and 4 were men, with ages between 17 and 23 years old. Of the total, 3 were from the Metropolitan Region, 3 from the Valparaiso Region, and 1 from the Bio-Bio Region. The sample was selected and managed through the National Disability Service, SENADIS.

Table 1. *Detailed list of the sample.*

#	Gender	Age	Vision Degree
1	F	20	Total Blindness
2	F	20	Total Blindness
3	M	17	Low Vision
4	M	18	Low Vision
5	F	19	Total Blindness
6	M	18	Total Blindness
7	M	23	Total Blindness

3.2 Instruments

A user satisfaction evaluation questionnaire regarding the use of the software was utilized for the end user evaluation, which consisted of an adaptation of the end user questionnaire "Software Usability Evaluation" designed by Sánchez (2003). This questionnaire is divided into two sections: In the first section, the users are asked to evaluate 12 sentences related to the use of the software, on a scale of 1 to 10, in which 1 corresponds to 'very unsatisfactory' and 10 corresponds to 'very satisfactory'. The sentences were the following: (1) "I like the software", (2) "The software is fun", (3) "The software is challenging", (4) "The software is motivating", (5) "The software makes me active", (6) "I felt I could control the situations in the software", (7) "The software is interactive", (8) "The software is easy to use", (9) "The software adjusts to my rhythm", (10) "I like the sounds in the software", (11) "The sounds of the software are clearly identifiable" and (12) "The sounds of the software give me information". In the second section, the users are presented with 6 open-ended questions, such as: "What did you like about the software?", "What did you dislike about the software?", "What would you add to the software?", "What do you think is the use of the software?", "Which other uses would you make of the software?" and "Did you like to use the numpad? Why or why not?". Also, an additional space was added to allow the users to express any opinions that they considered to be significant, and that they felt had been left out of the questionnaire.

Together with this questionnaire, a Non-Participant Observer questionnaire was also applied. Using this questionnaire, the facilitators recorded the following aspects for each user: start time and finish time of the experience, user's location in the room, times of the significant events that occurred, questions asked by the users regarding the use of the system, perceptions of the user's safety when using the system throughout the experience, use of the question navigation index, use of the "go to" functionality to navigate the questions, and interactions with the questions.

3.2 Procedure

The pilot project was carried out on December, 2010, together with the regular process for taking the PSU. This pilot project was carried out in 3 places at the same time (main Chilean regions): in the Republic of Mexico School in Santiago, Metropolitan Region, in the Quillota Terranova School in Quillota, Valparaiso Region, and in the Biobio F528 School, in Concepcion, Bio-Bio Region. The time for the implementation was 4 hours in each of these places.

The first stage of the procedure consisted in the installation of the workstation for the use of the AudioPSU system in each of the schools (see Fig. 4).

Afterwards the users entered into the room and were requested to take a seat at the workstation (see Fig. 5). Understanding the need to review the functionalities of the system regarding navigation with the numpad, adjusting the volume and testing that the application was working in optimal conditions, the facilitators proceeded to guide the users in exploring all of these points for about 20 minutes.

Afterwards, the composition and distribution of the contents of the PSU Language and Communication test within the AudioPSU software was described, explaining that the disposition of the sections was done in the same way as it is presented in the paper test. Then it was explained to the users that the time for taking the test was 2 hours, and the testing began.

Figure 4. *Testing Workstation with supporting material in Macro Type and Braille.*

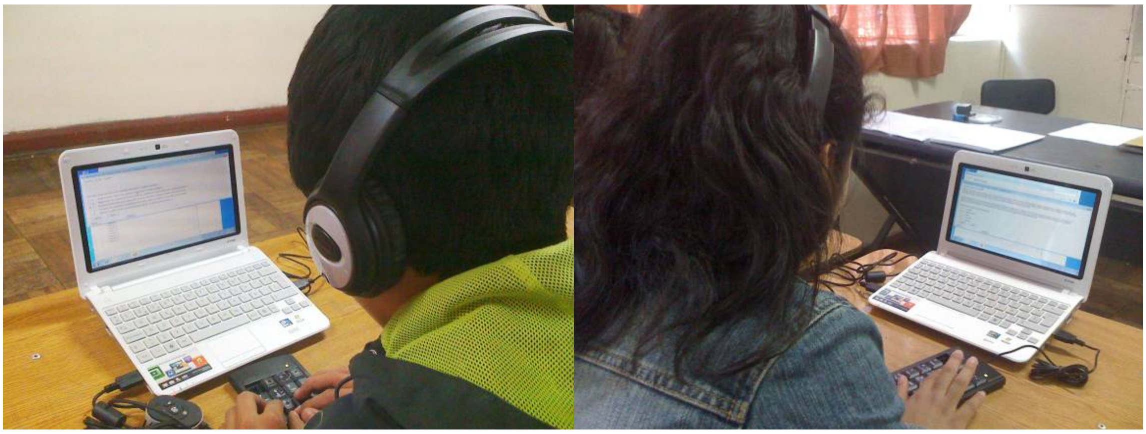

Figure 5. *Users with visual impairments interacting with AudioPSU.*

As support for using the software, the user had a guidebook in Braille or Macro Type (according to the degree of the user's vision) regarding the functioning of the AudioPSU application and the interaction keys of the numpad. Users were also provided with the test in Braille, giving them the opportunity to compare between these two modalities of accessing the information contained in the test.

In order to evaluate the users' performance in using the AudioPSU applications, the facilitators in the room used the Non-Participant Observation Questionnaire, recording the relevant information regarding the experience. Faced with any questions or concerns regarding the functioning of the software, facilitators provided the users with any necessary assistance in order to respond to possible questions or solve certain situations, such as audio interference, problems with using the numpad, and the duration of the battery charge for the equipment.

Once the users had finished the tests, the facilitators proceeded to apply the Software Usability for Blind Children Questionnaire to each user.

4. RESULTS

The purpose of this study was to design, implement and evaluate a digital pilot system that adapts the Chilean university entrance system, PSU, in the area of Language in Communication for people with disabilities based on audio and haptics. The results obtained based on the application of the end user usability questionnaire showed that AudioPSU is usable and understandable for users with visual impairments. In accordance with the characteristics of the sentences included in the questionnaire, the results were grouped into 3 different dimensions: "Satisfaction" (questions 1, 2, 3 and 4), "Control and Use" (questions 5, 6, 7, 8 and 9), and "Sounds" (questions 10, 11 and 12), all evaluated on a scale of 1 to 10 points (see Fig. 6.).

The “Satisfaction” dimension obtained an average of 7.0 points. In this dimension, the sentences that obtained the highest scores were: “The software is motivating” and “I like the software”, with averages of 8.3 and 7.3 points respectively. Considering that the test is made up of 80 questions, this shows that the system was able to motivate the users to be able to take the test.

The “Control and Use” dimension obtained an average of 7.8 points. The most significant results within this dimension correspond to the sentences “I felt I could control the situations in the software” and “The software is easy to use”, which obtained average scores of 9.0 and 7.7 points respectively. These results show the ease with which the users could use AudioPSU, due to the fact that the user remains in control of his or her navigation through the application. The lowest score corresponded to the sentence “The software adjusts to my rhythm”, which obtained an average of 7 points, which is due mainly to the fact that the first version of the system does not allow users to configure characteristics such as the speed and timbre of the voice utilized in the application.

The “Sounds” dimension obtained an average of 6.6 points. The significant results in this dimension correspond to the sentence “The software sounds are clearly identifiable” and “The sounds of the software give me information”, which obtained averages of 7.3 and 7.4 points respectively. The lowest result corresponds to the sentence “I like the sounds in the software”, which obtained an average of 5.1 points, due mainly to the fact that the voice utilized in the TTS was not agreeable to all users.

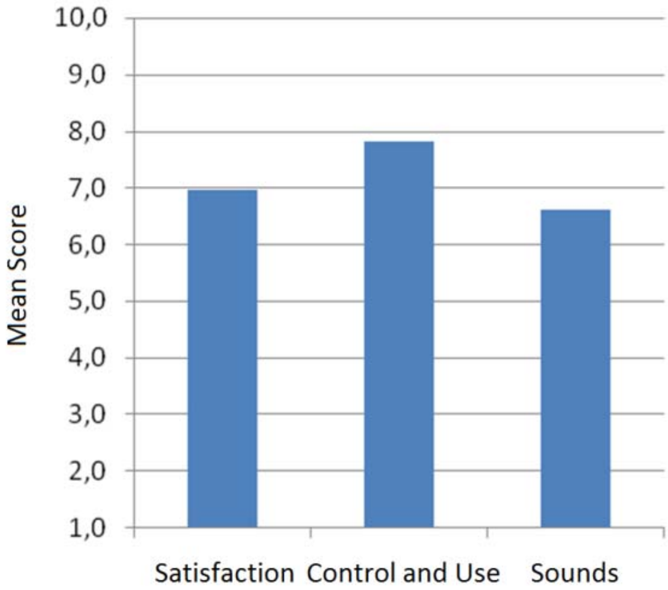

Figure 6. *Averages by category of the results of the end user questionnaire.*

Regarding the results corresponding to the open questions section, when asked “What did you like about the software?”, the users responded that the software is easy to use, that it allows them to take the test more autonomously, and that it presents users with a new opportunity for accessing the test. Participants also highlighted that the structure of the test in the AudioPSU software was the same as in the normal Language and Communication PSU test, as many had previously had the possibility to interact with the test, supported by sighted people in the case of the paper facsimiles and supported by a computer in the case of digital facsimiles of the PSU. When asked “What did you dislike about the software?”, users considered that an important issue is the voice used in the software, as in some cases this was not very fluid and they did not have control over the speed of the voice. As a result, when the user did not understand some word in a text, he or she had to listen to the text all over again, which took too much extra time in many cases.

When the users were asked, “What would you add to the software?”, the majority requested adding the option of controlling the speed of the voice, and making it more clear and fluid. When asked, “What do you think is the use of the software?” and “Which other uses would you make of the software?”, in general the users believed that the application could be used for any kind of test, such as in schools and universities, in order to facilitate study and evaluation processes. Finally, all of the users agreed that they liked using the numeric keyboard, as it is easier to use than the normal keyboard.

From the observations made during the test-taking process, it was noted that the users identified the keys on the numpad without any trouble; however, familiarization with the various functionalities of the software

is not automatic, and required a short tutorial period until the users were able to understand how to interact with and navigate the software. To overcome this problem, the fact that users could consult the Braille system user guide at any time was a big help, as they had the chance to resolve any problems by using their own strategies and means, without having to depend on the help of another person.

In general, the advanced functions of the software were not used, as navigation through the questions was performed sequentially. When the users wanted to return to a certain question, they achieved this through the "next" and "previous" buttons within the format of each question. Users were not observed to use any advanced functions such as to go to a specific question through the "+" key, or to return to the index through the "*" key.

Regarding the questions on the writing plan, it is very difficult for users to retain the correct order that the sentences should be in, to then seek out the answer choice that corresponds to the correct order.

5. CONCLUSIONS

The objective of this pilot study was fulfilled successfully. A digital pilot system that adapted the PSU in the area of Language and Communication was designed, implemented and evaluated, allowing people with visual impairments to participate inclusively, equitably and autonomously in the process for university selection.

Without a doubt, one of the advantages that AudioPSU presents compared to the current system for assisted test taking of the PSU is the degree of autonomy that the software provides people with visual impairments for navigating through the test, allowing them to make decisions and apply their knowledge. In addition, the system respects the working time that each user requires to respond to the questions, adjusting to their reading and hearing abilities.

In order to understand the functioning of the system and the numpad, it is necessary to perform a brief training session with users. This is held before taking the test, through instructions provided by the facilitators and with the support of accessible material, which allows users to learn of the various components of the system and the numpad, along with their respective functions.

It was observed that the system helps users to be able to map the structure of the PSU Language and Communication test, which contributes to their generating a mental model. However, a prior training session to learn how to use the system favored higher degrees of preparation and autonomy among the users.

The majority of the users were very accustomed to the use of synthesized voices as assistants in their experience with computer use. For this reason, the system must have voices that facilitate the change in the context of reading situations, both for extensive texts and specific actions regarding some questions within the test. In taking these requirements into consideration, it will be necessary to incorporate the option of reviewing the texts word for word, as well as implementing an accessible block of notes into a new iteration of the software, so that users are able to record their own notes or perhaps take audio notes. These aspects are proposed as future work in order to provide the user with a more fluid and user-friendly experience.

The users that participated in the pilot project felt nervous at first, due to the fact that they would have to perform all of the actions themselves, without any assistance as in the assisted test-taking modality. However, all throughout the experience they quickly understood the functionality of the system, being able to work autonomously without any problem, adjusting to their own work rhythm, and making their own decisions.

Regarding social integration, AudioPSU allows for integrating these users into the test-taking sessions within the same rooms used for sighted students. The system provides only the direct users with information, and does not generate any disruptive noises or interrupt the work and concentration of other test takers. In addition, in maintaining the same format as the normal PSU, users felt that they were finally considered able to interact with the test in the same way as a sighted person would take the paper test.

Finally, AudioPSU is positioned not only as an application that provides opportunities and access to the Chilean university admissions process, but as a tool that does not require a segregated social environment in order to function as well. Neither does it need any specific conditions that impede users from being included within the regular PSU test-taking process, offering an alternative option for special admissions processes designed for people with visual impairments.

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Novel electronic musical instrument for persons with cerebral palsy to play and enjoy together

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ABSTRACT

We have developed a novel musical instrument with storing pre-programmed music score in PC, named Cyber Musical Instrument with Score, "Cymis". Using Cymis, persons with neural or motor impairments such as cerebral palsy can play the piece easily. This instrument consists of monitor display, PC, MIDI sound source, speaker and interfaces, such as touch panel, switch and expiratory pressure sensing device. The field experiment commenced in 2008, and at present, ten facilities including National Hospital participate in the experiment. Assessment scales are constructed with 5 levels from 0 (almost no disability) to 4 (almost immobile), corresponding to the performing devices such as single input device to complex touch panel input method. Assessment was recorded during 27 months from Jan. 2009 to March 2011 in a facility. Results obtained from 44 clients (average age: 54.6) were as follows; no change of level was 24 (55%), dropped 1 level (improved functionally) was 19 (43%), up 1 level (decline functionally) was 1 (2 %). In conclusion, this paper presents the technology that is designed to be attractive to clients, that permits them to do an enjoyable activity that may not otherwise be possible for them, and that has shown some evidence to therapeutic effect.

1. INTRODUCTION

Movement disorder caused by brain damages such as cerebral palsy or brain disease prevents clients' participation in activities of daily life; for the sake of simplicity, we use "client" instead of an ill or disabled person in this paper. While rehabilitation approaches such as physiotherapy and occupational therapy have been usually utilized for improvement of the disorders, there is a need for efficient motor rehabilitation approaches. It has been shown that very rapid adaptation in cortical motor areas and auditory-sensorimotor circuits is caused by musical performance (Baumann et al, 2007). Music therapy, where the client could enjoy playing music in the rehabilitation program, is highly valuable and attractive because of the high motivational value of music. Recently, Schneider et al. (2008) and Rojo et al. (2011) demonstrated that the therapeutic approach using a music instrument is very effective in the motor skill rehabilitation of stroke patients. While musical instruments such as bell and drum are widely utilized in music therapy programs (Davis et al, 1999), conventional instruments such as violin, flute and etc. have been scarcely utilized for clients themselves to play music. In general, it is difficult or impossible for clients with severe disabilities to read a score and to play a conventional musical instrument. Since clients actually have an earnest request for music making, there is a significant body of work towards facilitating it for therapy and rehabilitation of the disabled. In Japan, for example, a kind of musical instrument named "music table", specially designed for the elderly and the disabled, had been developed by YAMAHA. In Sweden, a musical instrument developed by

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S Bunne such as “Swing Bar Guitar” is used in schools and elderly care institutions (www.leadinghealthcare.se). However, in a free database PubMed, we could not find any musical instruments for multiple-handicapped and were not able to find researches on musical making by handicapped.

Considering the background mentioned above, we aim at developing a musical instrument which clients with neural or motor impairments are able to play easily and enjoying together (Akazawa et al. 2011). This instrument is named Cyber Musical Instrument with Score “Cymis”, where musical score information necessary for the performance of each piece is stored within PC. It consists of a monitor display, PC, MIDI sound source, speakers and interfaces such as touch panel, switch and expiratory pressure sensing device. Using Cymis, clients without any previous musical experience are able to play a complex music, to enjoy playing and to progress in playing. There are three performance methods later described in 3 and various interfaces. One of the features is that the client can select both an interface and a performance method, considering degree of the dysfunction and progress of the performance. Consequently, improvements of the motor skill of the client can be objectively evaluated by tracing the history of performances and interfaces utilized by the client.

Figure 1. S*ystem structure of Cymis (Cyber Musical Instrument with Score.)*

2. SYSTEM STRUCTURE OF CYMIS

The system structure of Cymis is shown in Figure 1. Pre-programmed music score is stored in PC (Windows XP or 7), which is characteristic of Cymis. Music score is displayed on a monitor. The client can play music by simply pointing a touch screen from the leftmost note to the right in turn. Interface devices such as switch, touch panel and expiratory pressure sensing device can be connected to PC (Figure 2). With respect to switch, we have developed an air-bag type switch capable of responding to the force ranging from approximately 4mN to 6N. In addition, a switch using three-axis accelerator which responds to a slight motion of the body, and a soft switch with very small-sound producing have been also developed; both are not shown in Figure 1. Various kinds of commercially available mechanical switches are usable. Signals from the interface are sent to PC, MIDI control signal is created in PC, the signal is in turn sent to the MIDI tone generator (hardware or software), and finally a sound is produced by the tone generator. Tempo of the clients’ playing is always estimated and displayed on a monitor.

3. METHOD OF PERFORMANCE

There are three types of musical performances, named tempo-performance, melody-performance and rhythm-performance. The simplest is the tempo-performance. Switches which have two possible sates, ON and OFF are utilized. When the switch is moved ON at the beginning, the first beat in a piece is played. On moving the switch OFF, the music performance stops. Then, on moving again the switch ON, the second beat is performed in turn. The piece of music can be performed at even tempo with repeating this operation smoothly. For example, a conventional electric button with mechanical spring can be used as the switch; pressing the button makes the switch move ON, and turning back the button makes the switch move OFF. Therefore, pushing the button at a certain interval, clients can play the music piece at a steady tempo, which is almost similar to conventional playing.

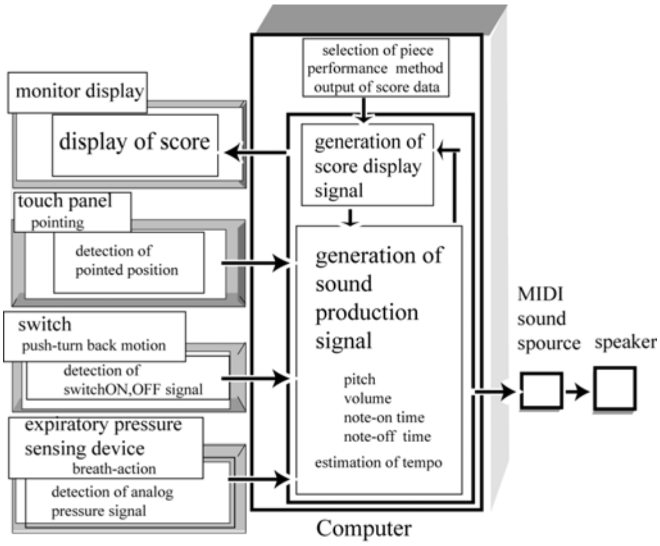

Figure 2. *Information flow showed with arrows. Functions and keywords are shown in boxes.*

In melody-performance, a music score is displayed on a monitor of a touch panel. When a note head displayed on the touch panel is pointed, the note is sounded with its pitch. The sound does not cease until the client stops pointing the touch panel. Properly pointing each note in succession from the beginning of the piece, the client can play it in the similar way to a conventional instrument. In addition, various sizes of larger squares entirely including a note are provided, instead of the note head. By using a touch panel with a force sensing function, the client can play varying the sound volume.

In rhythm-performance, an analog interface is utilized while a touch panel is not always necessary. For example, using both the developed expiratory device and a technique which is similar to a method of playing a wind instrument involving manipulation of the tongue, the client can play the piece, varying the sound volume.

As mentioned above, the client can select the performance method among three methods and an appropriate interface suitable to the degree of motor function and progress of the performance.

Figure 3. *A photograph of playing Cymis.*

4. PROCEDURE OF PERFORMANCE

Playing Cymis is executed as follows.

1. Execution of a computer program, cymis.exe.
2. Selection of a piece to be performed; more than one hundreds of pieces, including children's songs, songs for school, Japanese ballads, popular songs and classic music, are available.
3. Selection of an instrument for each part; there are 128 instruments in general MIDI Level 1.0. Features of each part can be adjusted in terms of MIDI volume, resonance, attack time, etc.
4. A score of the selected piece is displayed on a monitor (e.g., see Figure 3).
5. When the client operates interfaces, interface signals are sent to PC, and then processing is executed in PC, and finally MIDI signal is sent to the MIDI sound source controller (Figure 2).
6. MIDI output is sounded from a speaker.

7. Result of the performance can be stored as standard MIDI file in PC

A fast passage with many semiquavers is too difficult to play correctly by pointing each note. We have developed a software program of assisting the performance with touch panel, which is similar to Legato performance. The program helps the client play the passage so easily and have the same feeling of “phrasing” as the performance of conventional acoustic instruments.

5. RESULTS

Field experiments commenced in 2008 at a social welfare facility, and four persons with cerebral palsy played Cymis as experimental trials. Both clients and facilities have been increasing in number since then. At present, Cymis is utilized in ten facilities including National Institute of Special Needs Education, National Hospital, schools and social welfare facilities. Remarkable improvements of motor functions have been found in several facilities ;for example, a person with cerebral palsy and severe disabilities, aged 55 years, showed such a striking improvement that the middle finger which had scarcely moved started to move visibly in six months after the start of playing Cymis.

Assessment. Cymis has several devices to perform, not only touch panels but several numbers of switches can be used as playing device of computer. Pre-programmed score has also significant characteristics. That is; the way of performing Cymis has several steps e.g. one, two, three and four switches and different size of musical notes on the touch panels. Assessment scales are constructed with 5 levels from 0 (almost no disability) to 4 (almost immobile), corresponding to the performing devices such as single input device to complex touch panel input method. Assessment was recorded during 27 months from Jan. 2009 to March 2011 in a facility (54 clients, 34 cerebral palsy (63%), mean disability is level 5.76 (individual disability level is officially determined over the range from 0(no disability) to 6)).

Result: Results obtained from 44 clients (average age: 54.6) were as follows. Mean performing period was 15.6 months. No change of level was 24 (55%), Dropped 1 level (improved functionally) was 19 (43%), and Up 1 level (decline functionally) was 1(2%). Clients signing up Cymis as the day’s activity of the care-plan increased in number from 0 (2009) to 27 (2011). Thirty eights clients in this facility enjoyed playing Cymis 20~40 minutes a week and most of them wanted to play Cymis in a monthly birthday party.

Informed consent was obtained from each subject in all the facilities after they received a detailed explanation of the nature of the study

6. CONCLUSIONS

We have been developing an electronic musical instrument, Cymis, which was first used in a social welfare facility in 2008. Then, Cymis has been widely utilized by clients with cerebral palsy or with other disabilities. At present, field experiments have been executed in ten facilities including National Hospital. Remarkable results have been obtained in neurological rehabilitation as well as improving ADL.

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Virtual rehabilitation system for people with Parkinson's disease

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ABSTRACT

Patients that suffer from Parkinson's disease (PD) have different symptoms such as tremors, stiffness and slowness in the execution of first movements and absence of balance control. Traditional therapies show improvements in postural control, mobility and gait. Currently, the use of video games with low cost devices such as Nintendo® Wii Balance Board® and Kinect increases the rehabilitation process in PD patients against traditional rehabilitation. However, video games are designed for healthy people, and they are not appropriate in balance rehabilitation therapy. In this paper, we describe ABAR system, a custom, motivational and adaptive tool to rehabilitate PD patients, to help them recover from balance disorders and regain postural control. To achieve this goal, we will test patients at the beginning and at the end of the clinical study. Clinical tests include: Anterior Reach Test, the Time "Up and Go", the Stepping Test, the 30-second Sit-to Stand Test and functional reach test.

1. INTRODUCTION

Currently, Parkinson's disease (PD) affects approximately four million people worldwide; on average one out of 500 people has PD (UCB 2012). The main problems in PD patients are postural control, fear of falls (Bloem 2001) and balance disorders. As a result, patients have alterations in the daily life activities (ADL), increasing healthcare costs of countries and causing a high risk of mortality (Adkin 2003).

Other problems related to postural control in PD patients (depending on their pathology) are muscular stiffness, visuo-space injuries, loss of confidence, trembling and mobility reduction (Michalowska 2005) and postural control; these problems cause a reduction of physical and cognitive level (Carne 2005)

In the area of new technologies, systems based on virtual reality (VR) are promising tools in the field of motor rehabilitation (Burdea 2003). Nowadays, there are a lot of applications focused on functional motor rehabilitation for upper and lower extremities. This type of tools increases the performance of the rehabilitation process against traditional rehabilitation, which can be sometimes boring, tedious and repetitive (Merola 2011).

Balance Retraining Therapy (BRT) with postural biofeedback is a physical therapy to reduce dizziness and balance disorders (Nichols 1997) and can be applied increasing the steadiness, symmetry and dynamic stability. Systems used in BRT are composed of low cost components that expert clinicians can use easily. To obtain a low cost BRT researchers are using force platforms such as Nintendo® WBB (Gil-Gómez et al., 2011; Shih et al. 2010; Shih 2011) or devices such as Microsoft Kinect® which also focuses on PD patients (Esculier et al. 2012).

In our study we are creating a new system, Active Balance Rehabilitation (ABAR) with the help of clinical specialists in balance rehabilitation. The clinical specialists are physiotherapist and geriatricians of a hospital. The goals of ABAR system are: 1) to obtain a customizable tool for both the therapist and PD patients; 2) to provide and adaptive system for balance rehabilitation capable of showing the evolution of patients; 3) to offer a high motivational system within the virtual rehabilitation process. We hypothesize that

ABAR system increases the balance performance during the rehabilitation process in PD patients. Also, patients with other diseases associated with balance and postural problems could benefit from ABAR system.

2. METHODS

2.1 Interface

ABAR system was designed and developed using Conitec 2D and 3D game engine and it uses low cost devices such as a Nintendo® Wii Balance Board® (WBB), a bluetooth dongle, a loudspeakers, a 47" LCD TV and a standard PC. We selected a WBB because it is a device with specific characteristics, that can be used in the process of rehabilitation of parkinson's patients. Its characteristics are: intuitive interaction, easy to manage, portable, connection using Bluetooth and finally a low price.

The tool was programmed by lite-C program, using the script editor of Gamestudio A8. Visual feedback was obtained with virtual environments which were designed using Adobe Photoshop CS5 to create layers, backgrounds, virtual objects, buttons, text and also sprites. Audio feedback was included with a set of specific words (left, right, up, down, center, position).

The ABAR system consists of five specific games according to balance that patients will have to make: sitting position, standing in a static position and standing in a dynamic position. In a standing static position, the WBB will be placed on three different positions: tandem standing position (Figure 1a) standing position (Figure 1b) and floor standing position (Figure 1c)

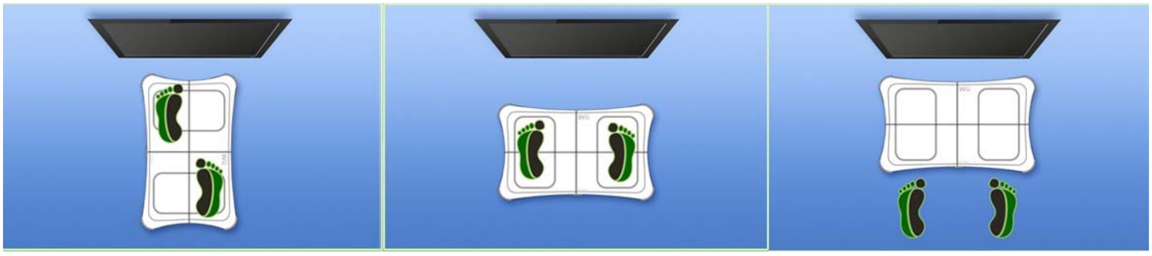

Figure 1. *Standing positions: figure 1a: tandem standing position, figure 1b normal standing position, figure 1c floor standing position.*

In sitting position, the patient should do antero-posterior and lateral weight transferences. To perform that, we designed the game "Ladybug" where the patient must capture randomly each x seconds a virtual candy appearing in four positions. At the first stage, the therapist selects the suitable parameters for the session (Figure 2, left), afterwards, the patient is placed on the WBB and plays (Figure 2, center); if the patient hits the target, the virtual environment displays a transparent candy and emits a sound cue to reinforce the motivation of patients, and if the patient misses the target, the system emits a characteristic sound cue to encourage him. Finally, after finishing the session, the game displays the number of hits/misses obtained (Figure 2, right). We can consider this information as a visual feedback that improves motivation of patients in the balance rehabilitation process.

Figure 2. *Stages of ladybug game. Left: setup stage, center: game stage, right: result stage.*

While standing in a static position, the patient makes lateral weight transferences and steps with right or left foot onto the WBB; to achieve this purpose, we have developed three specific games that therapist can select in every session: the motorboat, the burglar and the ghost buster, respectively. These games were developed with clinical experts according to the movements used in traditional rehabilitation program. (Figure 3) provides screenshots of the different games.

Figure 3. *Games in standing in a static position: figure 3a the motorboat, figure 3b the burglar, figure 3c the ghostbuster.*

In the Motorboat game (Figure 3a) the patient stands on the WBB and makes weight transferences to the left and to the right, according to the different targets that ABAR displays. In this game, the patient is required to have a good accuracy to hit the virtual target, because he needs to maintain the position and next to transfer his weight on the left or on the right. For this reason, the therapist needs to select the correct parameters to improve motivation of patients. In the Burglar game (Figure 3b), the therapist places the WBB in tandem position and the PD patient places one foot in front of the other in order to play the game; the subject moves the light beam toward the thief. The weight transferences are made forwards and backwards. In the Ghost buster game (Figure 3c), the patient steps with his feet the WBB in order to reach the ghost being displayed; the level of difficulty is determined by the speed of fall of the ghosts and also by the pressure on the WBB.

All games have a setup screen where therapist can select important parameters such as: interval of time between virtual targets, number of minutes per session, volume, number of games, time between games, and Audio Feedback. These parameters are very important to establish the level of difficulty in sessions and to obtain a high motivation.

The interaction of movements in virtual environments is made by weight transferences according to a previous calibration stage. In this phase, patients interact with the “calibration” virtual environment; ABAR system shows a panel with a dial, and the different pressures of feet and buttocks are stored for the active session. This information will be used to obtain the center of pressure (COP) and to customize the different sessions of the balance rehabilitation process (through internal algorithms that obtain the arithmetic mean of the different weight transferences). Other parameters that ABAR stores are: response time (the time necessary for the first response) and completion time (the needed time to accomplish the goal).

Figure 4. *Positions for different virtual game at the calibration stage: figure 4a Tandem standing position, figure 4b Sitting position, figure 4c floor standing position.*

2.2 Participants

At the moment, we are working on the selection of PD patients in a hospital of a small town. We have generated two groups of patients: the control group, composed of PD patients that will make traditional balance rehabilitation and the virtual group, that will use the ABAR system. The inclusion criteria are: subjects needs to obtain a score in the Mini Mental State Examination greater than 23 (>23), in order to ensure the correct participation; patients should be between 50 and 75 years old, patients should have gait and balance impairment, with a high risk of falls and stable medication use. The exclusion criteria are: patients with lower limb problems, clinical instability, patients with a history of falls and patient refusal.

2.3 Training programme

To interact in ABAR system, PD patients will play in different levels of difficulty according to the stage in the rehabilitation process. The program consists of 30 minutes of virtual rehabilitation and afterwards, 30

minutes of traditional rehabilitation, on a 3-5 days per week basis (20 total sessions). Each session is based on virtual games in sitting or standing position. Patients will be evaluated at the beginning and at the end of the clinical study. Clinical tests include: Anterior Reach Test (ART), the Time "Up and Go" Test, the Stepping Test (ST), the 30-second Sit-to Stand Test (30SST) and functional reach test (FRT).

3. CONCLUSIONS

The study presents ABAR system, a new tool designed specifically to reinforce and to improve the balance rehabilitation process in PD patients. To obtain this purpose, ABAR system has: 1) low cost devices such as WBB, a bluetooth dongle, and loudspeakers; 2) custom and motivational games for PD patients to make suitable weight transferences. At the moment, we are working in the testing stage, where patients are being recruited, and therapist/PD patients are providing changes to increase the functionality of ABAR system. We consider that the upcoming results will be promising because PD patients will be able to increase static and dynamic balance.

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Design of a novel virtual reality-based autism intervention system for facial emotional expressions identification

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ABSTRACT

A virtual reality (VR)-based system for evaluating facial emotion recognition ability of teenagers with autism spectrum disorders (ASD) is presented. This system is integrated with a non-contact eye tracker that allows investigation of eye gaze and eye physiological indices (e.g., blink rate) of the participants while they seek to identify the emotion displayed by the avatars in the VR environment. Performance and eye data of 12 participants (6 children with ASD and 6 typically developing children) are presented.

1. INTRODUCTION

Social communication impairments are among the core deficits of children with autism spectrum disorder (ASD) (Liu et al, 2008). Such social impairments include inability to recognize and understand facial emotional expressions (Dawson et al, 2005). Some suggest that there is significant impairment of understanding the emotional meaning of facial expressions in children with autism (Celani et al, 1999) while others seem to indicate otherwise (Castelli et al, 2005). Literature suggests that technological advancements enable application of emerging technology (Goodwin et al, 2008) such as virtual reality (VR) (Lahiri et al, 2011) and robotics (Bekele et al, 2011). Incorporating implicit cues from sensors such as eye tracker and measurement of peripheral physiological signals may help facilitating individualization and adaptation in ways that is not possible by current performance-based VR systems.

The objective of this work is twofold: (1) development and analysis of an innovative adaptive VR social system with eye tracking and physiological signals monitoring for affect and behavioral adaptation of future social tasks; and (2) performing a usability study for demonstrating the ability of the system in finding individual and group differences in eye gaze data and their implication in a VR-based social interaction and communication task. The scope of this paper is limited to the design of the new system, analysis of basic performance in emotion recognition, and understanding whether eye physiological and behavioral indices can be used to differentiate ASD and typically developing (TD) population for such tasks.

2. SYSTEM DESIGN

The system was designed for a task in which avatars narrated incidents/stories to a participant and then made relevant facial expressions to display a specific emotion. The system captured the participant's eye gaze as well as several peripheral physiological signals.

2.1 Development of the VR environment

The characters were designed to suit the age group that was targeted for the study, (13-17 years old). We designed the characters from mixamo (www.mixamo.com) and animated them in Maya. A total of 7 such avatars (4 males and 3 females) were created and used in this study. We used unity game engine (www.unity3d.com) as it allows customization in modeling, rigging and animations as it integrates seamlessly with 3D modeling and animation software pipeline such as Maya as long as they support exporting in standard formats such as FBX.

2.2 Development of facial emotional expressions

Individual facial emotion expressions were given 20 different weights to match them with 20 degrees of each emotion. The universally accepted Ekman's 7 emotional facial expressions (i.e., enjoyment, surprise, contempt, sadness, fear, disgust, and anger) (Ekman, 1993) and 7 phonetic visemes were created using set driven keys with each of them containing 20 weights. The visemes were for lip syncing to go with the storytelling before displaying the facial emotional expressions. Each trial as described in section III consisted of a story telling that might trigger the emotion expression that followed. Each of the 7 expression weights were divided into four animations that correspond to four intensity levels of the seven facial expressions. Each emotion expression was varied from neutral to 4 degrees of emotional expressions (low, medium, high, and extreme as judged by four observers before the study). A total of 16 storylines were manually lip-synced to an avatar and baked to key frames. All lip-syncs were then automatically copied to all the remaining avatars. Figure 1 shows the 4 degrees of an example emotion expression (surprise) with weights varied in steps of 5 from 5 to 20 in a scale of 0-20. The first one is a neutral face.

Figure 1. *Degrees of a surprise emotion expression (neutral, low, medium, high, and extreme).*

2.3 Integration of the VR social task system and sensory modules

The system in this study is composed of the main 3D scene running on unity for task presentation (VR task engine), eye tracker application (ET App), and physiological monitoring application (Physiology App, Figure 2). All three applications interact via a network interface in real-time.

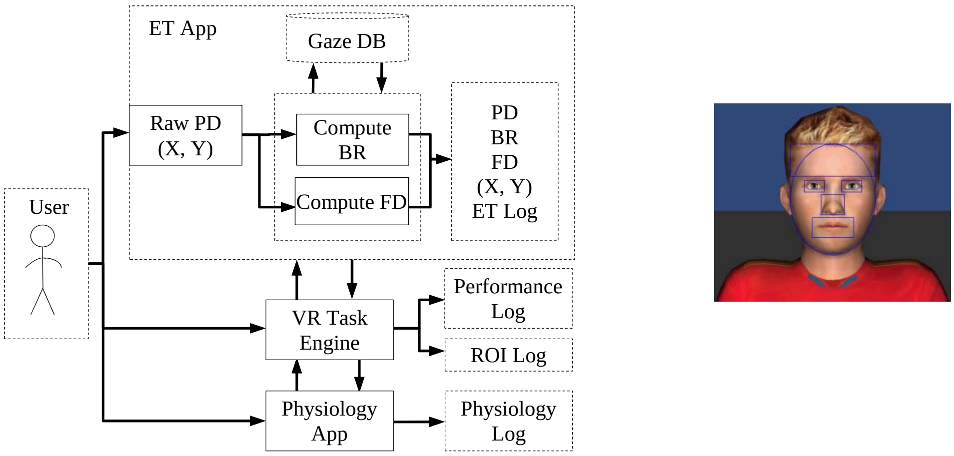

Figure 2. *VR-based system uses network interface between applications (left). The 6 face regions of interest (ROIs) (right) Note: PD: pupil diameter, BR: blink rate, FD: fixation duration, ET: eye tracker.*

The eye tracker used is the remote desktop eye tracker, Tobii X120, which enables tracking eyes non-invasively. The peripheral psychophysiological data was collected using a wireless non-invasive bio signal monitoring device called BioNomadix, by Biopac Inc. (www.biopac.com). BioNomadix is less restrictive in movement and more comfortable for participants than the wired-version. We developed the eye tracker application (ET App, Figure 2) that computes eye physiological (pupil diameter (PD) and blink rate (BR)) and behavioral (fixation durations (FD)) indices from the raw gaze data acquired from the eye tracker for each data point. These indices are known to correlate with one's engagement (Lahiri et al, 2011). The physiological monitoring application (Physiology App, Figure 2) collected raw data and logged it for offline analysis. We monitored 9 channels of peripheral physiological signals for future analysis.

2.4 Data analysis

The eye tracker data was analyzed offline to determine variations in gaze patterns between the children with ASD and the control group. A total of 5 ROIs (forehead, left and right eyes, nose, and mouth) were defined to meaningfully compare the data. Any region on the face outside of the 5 ROIs was considered other face region. The rest of the screen outside of the face was marked as non-face resulting in a total of 7 ROIs

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(Figure 2). The face ROI is the composite of the ellipsoid face and rectangular forehead. Each gaze point was clustered to the defined ROIs and a performance metric for each ROI was computed as the number of points lying in each ROI as a percentage of the total number of gaze points. The pupil diameter was filtered for noise rejection and interpolated linearly for missing data points. After filtering the raw fixation duration from noise spikes, it was classified in to normal fixation and saccade based on the duration. Spurious blinks were removed from the blink rate data using average range of human blink duration.

3. METHODS AND PROCEDURE

3.1 Usability study and Participants

A total of 6 participants with ASD (1 female and 5 males) and 6 TD (1 female and 5 males) have completed the study. Average age of ASD participants was 14.83 and that of TD participants was 14.5.

3.2 Task and procedure

The presented task was to identify different kinds of facial emotional expressions as displayed by the avatars. Each of the 7 avatars can display all the seven emotions in addition to 16 lip-synced story telling capabilities. There were 28 trials in a typical session corresponding to 4 (the four emotion strengths) times each 7 emotions. Each trial started with a brief (1 minute long) story that might trigger the emotion that follows. The vocal tone and the story lines were carefully selected not to influence the participant's decision making. The participant was expected to make decisions based on only the last 5 seconds of emotion expression after a minute or more of the story. After each trial was over, a menu selection of all the 7 emotions appeared for the participant to choose the emotion he/she thought the avatar just displayed.

4. RESULTS

The following scatter and fixation-saccade diagram shows example raw and behavioral eye data of a participant with autism and a typically developing participant.

Figure 3. *Scatter and fixation-saccade diagrams for of a particular trial of participant with ASD (middle) and that of a TD participant (left and right).*

4.1 Face and Non-Face regions comparisons

Clustering of the gaze in to the 5 different regions, other facial areas and non-face areas have been analyzed. Results suggest that the TD group spent slightly more time inside the defined ROIs while the ASD group spent a slightly more time on other facial regions. The ASD group also spent slightly longer time outside of the face region. Significant differences were observed on the mouth and forehead regions (Figure 4). The TD group spent 15.09% ($p < 0.05$) more time on the mouth than their ASD matches. Whereas the ASD group spent 16.34% ($p < 0.05$) more time on the forehead region than their TD counterparts. Given that the majority of time (about 1 minute) was spent on the story telling while only the 5 seconds were dedicated to emotional expression by the avatar, looking more to the mouth area was naturally expected. The results are consistent with ASD population focus on context irrelevant areas.

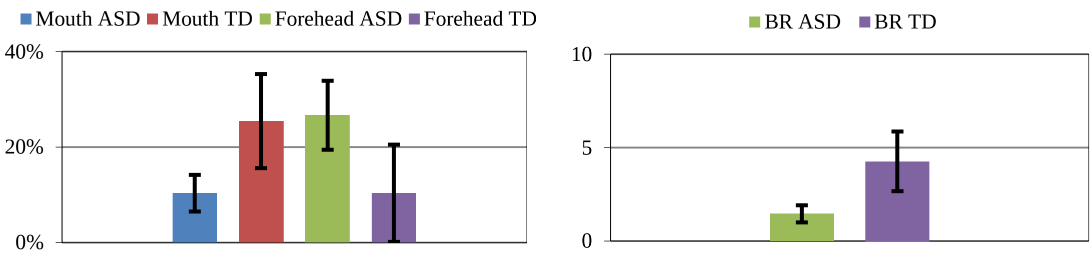

Figure 4. *Plot of percentage time spent on mouth and forehead area and BR by both ASD and TD groups.*

4.2 Behavioral and Physiological Indices

Among the eye physiological indices, blink rate (BR) is the one with significant difference between the two groups. The ASD group has far less (2.81 less blinks per trial, $p < 0.05$) blinks on average per trial than the TD group. The observation of the TD group is consistent with literature which suggests during tasks such as reading, blink rate decreases to 4.5 per minute (Bentivoglio, 1997). The unusually lower result of the ASD group might be attributed to a "sticky" attention, typically exhibited by children with autism.

4.3 Performance and confidence

There were two measures of performance. Correct identification of the presented emotions and how much confident the participant was in their choice. The ASD group performed with higher correctness percentage (13.1% more) than the TD group while the teenagers in the TD group were (11.37% more) more confident in their choices than their ASD. The performance result is inconsistent with expectations, however, factors such as relatively short duration (about 5 sec) of the emotional expression as compared to the story telling portion (close to a minute) could contribute to the outcome. TD teenagers trying to guess the succeeding emotion from the story could also be a possible confounding factor as the story didn't necessarily lead to the emotional expression displayed in a trial. However, these differences were not statistically significant.

5. CONCLUSIONS

We have designed a novel VR-based ASD intervention system that can create highly controlled and versatile emotional expressions. This system integrates an eye tracker to allow gaze analysis to investigate how gaze data and emotion recognition ability are correlated. It also integrates a peripheral physiological data acquisition system. Results of the preliminary analysis of the pilot study to evaluate the capability of the system are encouraging. However, there are several limitations of the current study that warrant consideration. Certainly a much larger study of the current system would be needed to understand how our current findings impact areas of core deficit for individuals with ASD. Additionally, a fundamental challenge to this system is that realistic social interactions, a target for this intervention tool, needs to be developed for demonstrating robust, meaningful change within and more importantly outside the VR platform.

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Subject anonymisation in video reporting: is animation an option?

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ABSTRACT

This short-paper contribution questions the potential of a simple automated video-to-animation rotoscoping technique to provide subject anonymity and confidentiality to conform to ethical regulations whilst maintaining sufficient portraiture data to convey research outcome. This can be especially useful for presenting to young researchers whose limited experiences can restrict their ability to draw association between a treatment and subject profile when solely presented textually and/or verbally. The goal of the paper is to provoke discussions on the subject. It is speculated that given a satisfactory result researchers will more easily be able to illustrate in-session action, responses to treatment, and other outcomes.

1. INTRODUCTION

Participant pseudonyms, characteristics (such as gender or occupation), and location of a research study are often changed to comply with ethical requirements. Thus, identities are concealed and the confidentiality of the data provided by participants is maintained (Crow and Wiles, 2008).

Observing facial data and non-verbal body language are significant for assessing human subjects in e.g. rehabilitation research sessions. Video recordings are commonly used to archive such sessions for subsequent analysis. Especially in qualitative research, findings can be illustrated to other researchers in the field of study by sharing an extracted single image or a video clip. However, ethical considerations need to be addressed in order to share outside of the research team.

A single image can quickly be treated to hide identity, but to similarly treat a video is an enduring process due to the numbers of frames involved. Another challenge is that the editing can delete important data such that the findings are not supported as well as if the original material was used.

This extended abstract posits how the technique of Rotoscoping can address these challenges. The technique is similar to creating a drawn image from tracing over a source image (see Baimbridge, 2001). The technique can be used to turn a movie into an animation and a version has been used in Hollywood movies e.g. 'Waking Life' (Linklater, 2001) and 'A Scanner Darkly' (Linklater, 2006).

Figure 1. *Left: Source image from movie – Middle: Airbrush preset – Right: Outlines only present (DancingGirlMov) by Studio Artist [synthetik.com].*

Figure 2. *Left: Backlight edges preset – Middle: Goth preset – Right: Heat vision preset*

Problematic is that in some of the generated material the identity of the source is not obscured, thus possibly being unacceptable for ethics. However, as Rotoscoping is available as a software program plugin where parameters can be adjusted to incrementally obscure an identity, a balance between the adjustments made to reduce identity whilst maintaining available data for a satisfactory analysis needs to be case-specifically explored. Figure 1 and 2 illustrates the technique via simple pre-sets.

Experiences inform how healthcare professionals, therapists and carers witness a presentation and visualise association to one of their patients. Young researchers have limited experiences to be able to draw such associations. Thus, video presentations can have high impact value on the next generation researchers. Similarly, with the introduction and adaptation of novel devices in healthcare research it is suggested that experienced researchers have a preference to view intervention videos to learn new methods and witness applied practice so as to envisage direct associations to their patients.

An additional query is if this goal is achieved then would the technique be accepted by the research community, both those who establish ethical guidelines and the researchers that would need to edit their source videos.

Figure 3. *Courtroom sketch by Butch Krieger – source Wikimedia Commons ©http://www.butchkrieger.com*

A discussion questions an analogy of courtroom artists whose remit is to illustrate sensitive legal situations where cameras and in-court sketching are not permitted (e.g. figure 3). Single image depictions are of a similar nature as the Rotoscoping technique is capable of generating, however, in court cases it is plausible to assume that the public and media know the person(s) involved in the image. However, courtroom illustrations (or courtroom art) have been criticized as depicting fiction not fact (e.g. see Solnik, 2009). The Rotoscoping automated technique more accurately depicts fact as the source is directly responsible for the computer-generated animation.

2. CONCLUSION

This contribution is a work-in-progress that posits the question of whether animating research video can be considered as an option to address ethical considerations of subject anonymity in sensitive research reporting. However, if considered, it is likely a subject's identity can be speculated via certain animation techniques that uses source video if the subject is known to the audience, e.g. the rotoscoping technique as used in the movie industry such as 'Waking Life' (Linklater, 2001) and 'A Scanner Darkly' (Linklater, 2006). Is such a technique suitable for research reporting when text and words are not enough to determine idiosyncratic condition if so what level of depersonalisation of portraiture will make it a feasible option. The case is argued that "text and words are not enough".

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Markerless motion tracking: MS Kinect and Organic Motion OpenStage

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ABSTRACT

This contribution focuses on the Associated Technologies aspect of the ICDVRAT event. Two industry leading markerless motion capture systems are examined that offer advancement in the field of rehabilitation. Residing at each end of the cost continuum, technical differences such as 3D versus 360 degree capture, latency, accuracy and other issues are discussed. The plusses and minuses are presented including reflections on the evolution of the MS Kinect to be a stand-alone device for PC with a SDK to offer access for creative programmers to develop systems for disabled users. A conclusion is how the SDK enables half-torso and mirroring calibrations offering new opportunities for wheelchair users.

1. INTRODUCTION

Behind this brief position contribution is a mature body of research that evolved bespoke motion sensing devices to enable markerless gesture control of multimedia. Games (movement mapped to gameplay); robotics (movement control of motor-driven multimedia devices); and creative expression (e.g. movement control of digital music, robotic devices, digital painting, effects etc.) have been explored. An international patent, an independent commercial product, and a spin out company resulted from the research (Brooks and Sorensen, 2005). Upon this background two contemporary motion capture systems are explored, specifically the Kinect and the Organic Motion systems. The aim is to provoke a debate on requirements for use within rehabilitation of such technologies - both as a tool to motivate and optimize engagement as well as a means to assess use and potential end-user development. To support the emerging communities of users, i.e. trainers/educators/therapists/carers/families, who are interested in ICT applied in their work, a series of papers are being written to detail the choices that are available for communication apparatus and method in line with Brooks and Sorensen (2005). This contribution focuses on specific camera-based systems that empower control of avatars without using wearable or held equipment, i.e. markers, handsets, or other tangible artefacts that can impede in complex situations such as rehabilitation.

2. TECHNOLOGIES

With the advent of markerless motion control becoming commercially available to the masses at an affordable price, this paper compares two systems at each end of the price spectrum so that potential adopters may have insight upon which to consider potentials to supplement traditional rehabilitation. The first system presented is the affordable Microsoft Kinect, which is available either bundled with the MS X-Box or as a stand-alone Windows PC device with a supplied SDK and drivers. The second system, which is at the high end of the price range, is the OpenStage® V2.0 Markerless Motion Capture System by Organic Motion.

2.1 Kinect

The MS Kinect system is well documented as the first consumer-grade application that uses a pattern of projected infrared-points to generate a dense 3D-Image to capture information from a scene. The user's whole or upper body can be calibrated to permit limb motion control via skeletal mapping. Whilst the level of markerless data accuracy is not as high as high end marker-based systems it is impressive relying on interpretation and predictive algorithms to determine the most probably upcoming pose. The Kinect technology is overviewed in table 1. This technique predicts the most probably skeleton by building on its experience and pre-programmed kinematics models. This skeleton is then outfitted as a 3D avatar.

Limitations reported to date are of ‘blob’ detection rather than specific details of limb, e.g. fingers versus hand location. This is improved in the new Kinect for Windows SDK.

Table 1. *Comparatives of Kinect & Organic Motion.*

PARAMETER	KINECT (MS X-BOX)	ORGANIC MOTION
SPEED	30 fps limited tracking of fast moves	Adjustable from 30 to 120 fps to track
ACCURACY	Low – Not a real 3d mocap	High – In the mm range
FULL 3D TRACKING	No, based in predictive algorithms	Yes, provides full 3D real time data
BONE SIZING	Approximation	Accurate
FOOT TRACKING	Unknown	Yes
FINGER TRACKING	Unknown	No
HEAD TRACKING	Limited	Yes
BIOMECHANICS APPLICATIONS	No	Yes
360 DEGREE VIEW	No	Yes
LATENCY	250 millisecs	50 – 100 millisecs
RESOLUTION	640x480	8-18 cameras, 640x480
# OF PEOPLE	More than 2	More than 2
SCANNING AREA	1.2–3.5 m	Scalable, up to 5m by 5m

2.2 Organic Motion

OpenStage harnesses Organic Motion’s core computer vision technology, enabling computers to cognitively “see” people’s complex movements and generate accurate 3D tracking data in real-time. A Video Sub-System acquires lens and space calibrated video from 8 - 18 cameras and delivers these synchronized streams to the 3D Reconstruction Processor. The 3D Reconstruction System turns the 2D video streams into 3D point and surface clouds by triangulating the various 2D viewpoints. In this way the 3D Reconstruction System acts much like a 3D scanner. The final step involves “recognizing” the human figure in this 3D data cloud. Here Organic Motion uses a complex rules based approach which maps a 3D humanoid skeleton into the data. The output data OpenStage delivers is the X, Y and Z positions and orientation of 21 segments of this skeleton. This information is then ready to be loaded directly via plug-ins or SDK into any form of animation software, game engine, biomechanical or other processing software, all in real-time. Tracking customized objects, non-typical humans, or non-human shapes requires the modelling of new character fitting systems, which OpenStage offers as part of its new software architecture.

3. DISCUSSION

The Kinect sold 18 million units in 2011. Microsoft have responded to the demand of the ‘hacking’ community by launching “The Kinect Effect” informing of use of the peripheral beyond traditional games, e.g. in USA within therapy sessions with children diagnosed with autism (Lakeside Center for Autism), in UK hospitals treating Stroke patients (Royal Berkshire), in Spain within hospital operating rooms where doctors navigate MRIs and CAT scans (Tedesys) … there is a long list. The built in biofeedback for the player’s self-monitoring advances this field.

Organic Motion sold systems in over 20 countries worldwide, and is used in both commercial and academic settings for multiple applications in various markets including: Digital Media & Arts (Animation,

Game Development, VFX); Life Sciences (Bioengineering, Physical Therapy and Rehab, Neuroscience, Sport); Training and Simulation (Military and Defence); Public Installations (Theme Parks, Museums). OpenStage interfaces with various 3D animation systems, 3D game engines and Virtual World systems and 3D immersive visuals, biofeedback and other applications. For therapeutic applications, movement 'rules' may be incorporated to encourage people to be more actively engaged in the recovery regime, thus, improving outcomes and reducing recovery times. The high accuracy of OpenStage allows clinicians and researchers to identify multi-level movement disorders, develop predictive models of pathology and gather statistical relevant data for long-term improvements. OpenStage was recently used by a research group at the Rush University Medical Center in Chicago for a study to quantify Hyperkinesis and Stereotypies in Males with Fragile X Syndrome.

4. CONCLUSIONS

Evaluating a dancer's performance via Kinect-based skeleton tracking is reported in Alexiadis et al. (2011). Matthias Wölfel from the Karlsruhe University for Arts and Design provides the Kinetic Space tool (*http://kineticspace.googlecode.com*) that enables automatic recognition of customized gestures using depth images. This provides a visual feedback how well individual body parts resemble a given gesture. Similarly the Organic Motion is used across related disciplines. Markerless-motion tracking has clear impact in rehabilitation especially when the SDK enables access to adapt source, mapping and content data with real-time humanoid feedback. The half-torso and mirroring calibrations with the Windows PC Kinect are deemed to offer new opportunities for wheelchair users that will be further explored in the future research.

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Perceptual game controllers and fibromyalgia studies

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ABSTRACT

This pilot study investigated gesture-based control of video games to promote and motivate self-driven home-based aerobic exercise (AE) training regimes to improve pain threshold associated to fibromyalgia. 10 patients were randomized to 10 sessions each led by a non-medical 'game-savvy' PhD Medialogy student. Control was treatment-as-usual (TAU) patients via the patient's doctor who conducted pre- and post- interviews, tests, and VAS registrations of pain, disturbed sleep, lack of energy, and depression. Included was patient-reported global subjective improvement or otherwise. A Nintendo Wii was used with a sports compilation game 'Sports Resort' with the Wiimote MotionPlus Accessory to increase accuracy of gesture. Facilitator in vivo noted observations and the doctors' research were supplemented by multiple angle (3) video cameras synchronized to the game play for correlation analysis. Outcome measures were at baseline and completion. Short-term results were positive of those patients who completed the study (n = 2). 50% drop out at study commencement suggested a sceptical patient attitude. Further drop outs (n = 3) were due to a car accident (n = 1) and recurrence of pain (n = 2). Both patients who completed showed significant motion improvements and each purchased a Wii for home training following the study. Follow up interviews and tests are planned to question compliance and long-term outcomes. A follow-on comparative study with 39 patients was conducted with two occupational therapist students replacing the Medialogy student as session facilitator. Three game platforms were studied: the MS Kinect, Sony MOVE, and Nintendo Wii, with 5 game sessions of one hour being played by each patient in regular lab visits (=15 sessions each). This is reported separately with preliminary findings indicating tendencies in line with this short paper. A more detailed report will be included in the publication of the final work as a whole.

1. INTRODUCTION

Fibromyalgia is a lifelong condition involving widespread musculoskeletal pain and tenderness, fatigue, sleep disturbance, and functional impairment, without any known structural or inflammatory cause. This problem is costly in terms of consultations, prescriptions and sick leave. The main aims of therapy are to reduce symptoms, to improve function, and to help patients adapt to the condition. The medical community are split between treatments. A goal of this study was to augment the patient's motivation to participate and exercise and thus raise their energy level, tolerance and threshold before onset of the fibromyalgia pain. By using a contemporary, affordable, and widely popular gaming platform (Nintendo Wii) it was envisaged that new opportunities to achieve these goals as well as to socially interact via playing with family members and friends would further motivate and sustain the intervention strategy. Self-driven home-training regimes were targeted.

Using an exploratory approach, Pasch et al. (2009) investigated the influence of movement on how gamers experience video games (Nintendo Wii Boxing game) through the systematic collection and analysis of data obtained from interviews, questionnaires, video observations and a motion capture system. Achievement and relaxation were gamer reported motivators of the play, which was evident in the gameplay via two corresponding movement control strategies. Outcomes from this study point to four movement-specific items influencing immersion in movement-based interaction: natural control, mimicry of movements, proprioceptive feedback, and physical challenge. These were reflected from a design perspective in respect of physical activity and emotional well-being. Analogizing from this study and directing at fibromyalgia, we additionally reflect from input from the patients' doctor.

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Justifying the use of a gesture-controlled game (held handset) in this context we relate to the studies on Energy Expenditure (EE) during Wii Sports game activities of TD adults reported positively by Miyachi et al. (2010). Hurkmans et al. (2010; 2011) similarly report on cerebral palsy and chronic stroke patients using the Wii respectively claiming “useful as treatment to promote more active and healthful lifestyles in these patients” and “sufficient for maintaining and improving health in this population”. However, we found limited articles on the exploration of video games as a supplement for traditional fibromyalgia treatments.

2. METHOD

The patients were guided to be able to play the games. The Wii ‘Sports Resort’ compendium game was used where patients could select the specific gameplay and level. A 107 cm screen size TV was used for the patient to monitor gameplay and to give a mirroring effect to motion, which had been found optimal in prior studies (Brooks & Petersson, 2005). The area was set-up with a tape marker for the patients’ gameplay start position consistency between sessions. Three cameras with different viewing angles were routed to 1, 2, and 3 inputs of a Roland V-4 four channel video mixer (figure 1). The component output from the game console was routed to the channel 4 input as well as to the TV. This was to enable a quadrant view of patient activity so that stimuli and responses could be automatically synchronized to optimize intervention/interaction analysis. The facilitator supported where necessary targeting fun experiences from the play situation rather than evoking a therapeutic situation. The Wiimote handset was enhanced via the MotionPlus accessory for extra sensitivity.

VAS registrations of: pain, disturbed sleep, lack of energy, and depression were among the tests, conducted by the patients’ doctor, as well as interviews questioning global subjective improvement. Outcome measures and interviews were at baseline and at treatment completion.

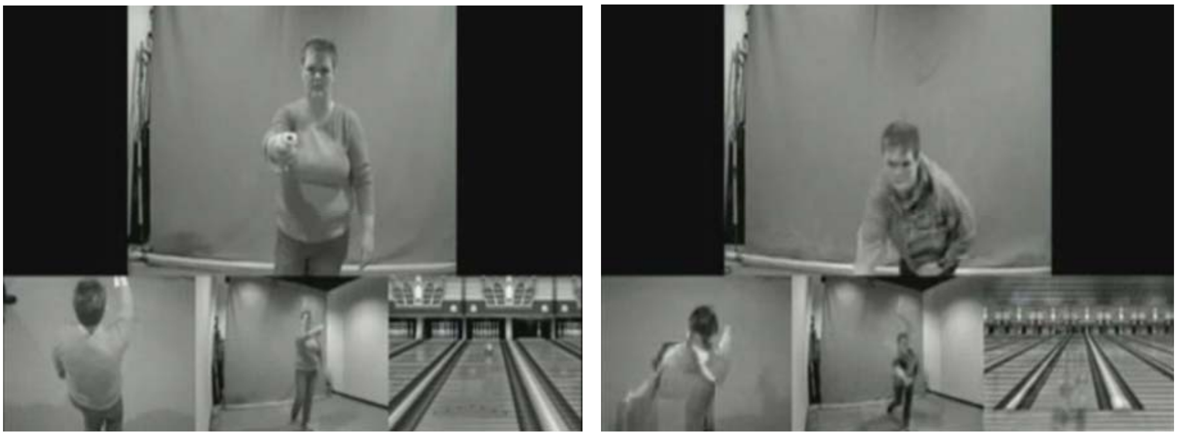

Figure 1. *Four screen view with synchronized gameplay lower right. Left image is session 2, i.e. after acquainted. The right image indicates change of body dynamic also indicated by motion blur by final session.*

3. RESULTS, DISCUSSION & CONCLUSIONS

Videos were analysed and further viewed by a representative from the Danish Fibromyalgia union. The videos clearly indicated a common pattern that, following initial trepidation and caution by the patients, and once comfortable, the patients’ dynamic motions were stimulated via the gameplay so that a new level of engagement and motion was evident by the end of each session. The Danish Fibromyalgia union expert evaluated positively. This ‘pushing of own limits’ via alternative channels of stimuli is typical of the SoundScapes research findings over the last 25 years with gesture control. The findings were substantiated by the medical doctor who reported significant results between pre- and post- VAS outcomes and other collected data. The video game engaged the patients to previously non-seen dynamics of motion gesture and participation. They also had lots of fun both in the gameplay and interactions with the facilitator that was analysed as offering positive reinforcement and scaffolding for the patient playing the game (the follow-on study indicated the differences between a therapist and a non-therapist scaffolding). One patient reported using the training sessions as a family event (she brought her daughters to the sessions for encouragement). The other patient used sessions as a self-training regime without family support and would change into a Lycra aerobics outfit. Her approach was that this was her private time and space. Both of these were self-driven without researcher intervention or suggestion.

Notable was that the two patients that completed all sessions each purchased the Nintendo Wii for home use. This is in line with a report by Dr. Ben Hertz, a director of Occupational Therapy at the Medical College Georgia (2008), who explained that in a study with Parkinson's disease and the Wii participants showed significant improvements in rigidity, movement, fine motor skills and energy levels. Perhaps most impressively, most participants' depression levels decreased to zero. The report states that about 60 per cent of the study participants decided to buy a Wii themselves, suggesting that that speaks volumes for how the study made them feel. This correlates with our Denmark study with fibromyalgia.

The pilot study investigation of whether gesture-based control of video games can promote and motivate self-driven home-based aerobic exercise (AE) training regimes to improve pain threshold associated to fibromyalgia is positive. This is in line with other studies exploring video games in rehabilitation. Follow up interviews are planned to question home compliance and longer-term outcomes with these patients.

The complexity of researching a disabling condition such as fibromyalgia where much is still being debated on the disease itself (e.g. psychosomatic versus medication/exercise) as well as the innate challenges of assessing human condition in general, means that each case is individual when considering progress. Whilst initial results are positive, a reflection on the generic viability against the TAU control in such a limited study is speculative due to the large drop out of 8 from 10 patients. However, the significance of the findings in this pilot study led to a follow-on comparative study (handheld device for motion tracking versus non-handheld) with 39 patients under the same doctor. It was conducted with two occupational therapist students replacing the Medialogy student as session facilitator. Three game platforms were studied: the MS Kinect (non-handheld), Sony MOVE (handheld), and Nintendo Wii (handheld), with 5 game sessions of one hour being played by each patient in regular lab visits (total =15 sessions each patient).

A more detailed report from this pilot study and the follow-on investigation will be included in the publication of the final work as a whole.

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Advantages of haptic feedback in virtual reality supported balance training: a pilot study

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ABSTRACT

Repetitive and goal based task supported with virtual reality technology have proven successful in balance training of stroke population. However, adding a haptic experience can besides increasing the difficulty level of the task enable postural responses assessment. We demonstrated in a single subject with stroke that haptic feedback can be used not only for interaction with virtual environment, but also for the assessment of postural responses. After the virtual reality and standing frame supported balance training the subject was introduced to the haptic floor. The acceleration of the standing frame/body provided sufficient information to identify the direction of the postural response that could be critical for fall. The outcomes were comparable with neurologically intact population and could be applied for objective postural response evaluation.

1. INTRODUCTION

Restoration of static and dynamic balance is the major issue for rehabilitation in stroke population. The outcomes have demonstrated that intensive therapy with repetitive and targeted tasks should be applied (Kwakkel et al, 1999). Appropriate assisting devices (active e.g. KineAssistTM, kinea design llc, USA or passive e.g. BalanceTrainer, medica MedizinTechnik, Germany) can assure safety, body weight support, trunk and pelvis stabilization. The active device can maintain the desired posture, but the passive devices only limiting the balance range require certain amount of subject's activity. However, both types can assure repeatable conditions and free the therapist of strenuous manual work. In combination with the information-communication technologies (ICT) the goal based tasks are carried out in virtual reality (VR), enabling the user to gradually increase the difficulty level, to supervise the repeatability of the rehabilitation process and to change the virtual environment (VE) without changing the basic goal of the task (Holden et al, 2005). Several authors reported on improvement of motor functions in gait, posture and balance (Yang et al, 2008, Visell et al, 2009, Cikajlo et al, 2009, 2012) using VR. Adding a haptic interface to the VR task may enhance action/reaction activities in lower extremities (Vissel et al, 2009). We introduced a haptic floor (Cikajlo et al 2011) to the VR supported balance training, which required from the subject to respond to the postural perturbation at the moment of collision with the obstacle in the virtual environment. The subject needed to activate the postural mechanisms (Jacobs et al, 2007) to return to the equilibrium without lifting or moving the feet. The purpose of the paper is to present the added value of the haptic floor in VR supported balance training. Besides clinical tests we indirectly measured the acceleration and tilt of the subject and acceleration of the haptic floor during task execution and expected that we can evaluate the postural response at the impact with the virtual obstacle.

2. METHODS

The haptic floor was designed as an add-on for the passive dynamic balance training frame (BTF). The passive BTF (Matjačić et al, 2008) enabled the participating subjects safe hands-free balancing during up right standing within pre-set limits. The user could also set up the mechanical stiffness of the supporting frame to increase the level of support. The tilt of the BTF resulted in the immediate action in the designed VE (VRML 2.0, blaxxun contact plug-in – www.blaxxun.com).

2.1 *Equipment and control design*

A passive BTF (Balance- Trainer, medica Medizintechnik GmbH, Germany, Matjačić et al, 2008) enabled full support for the subject during independent balance training. The BTF consists of aluminium frame, fixed to the steel base construction on four wheels and passive controllable springs defining the stiffness of the two degrees of freedom (2 DOF) standing frame (Fig. 1) and enable tilting in sagittal and frontal plane for 15°. The tilt of the BTF and acceleration of BTF and haptic floor were measured by 3- axis sensor (MTx, Xsens, Enchede, Netherlands). Haptic force plates were driven by DC motors (Maxon DC RE40, 150W, Switzerland) with reduction gearbox (Maxon, Planetary Gearhead GP 52, Switzerland) moving the aluminum plate in 2 degrees of freedom (Fig 1.). Each DC motor was equipped with encoder (Maxon Encoder HEDS 5540, Switzerland), A,B and index signals were measured with high-speed digital I/O (National Instruments (NI) 9403, USA) and decoded with software quadrature decoder written in Labview 8.5 FPGA (National Instruments). The haptic floor control was embedded in real-time (RT) controller (NI cRIO-9014, USA). The analogue output module (NI 9263 AO, USA) served as an actuator output for DC motors and was amplified with the servo amplifier Maxon 4-Q-DC servo amplifier (ADS 50/10, pulsed (PWM) 4-Q-DC Servo amplifier 50 V / 10 A).

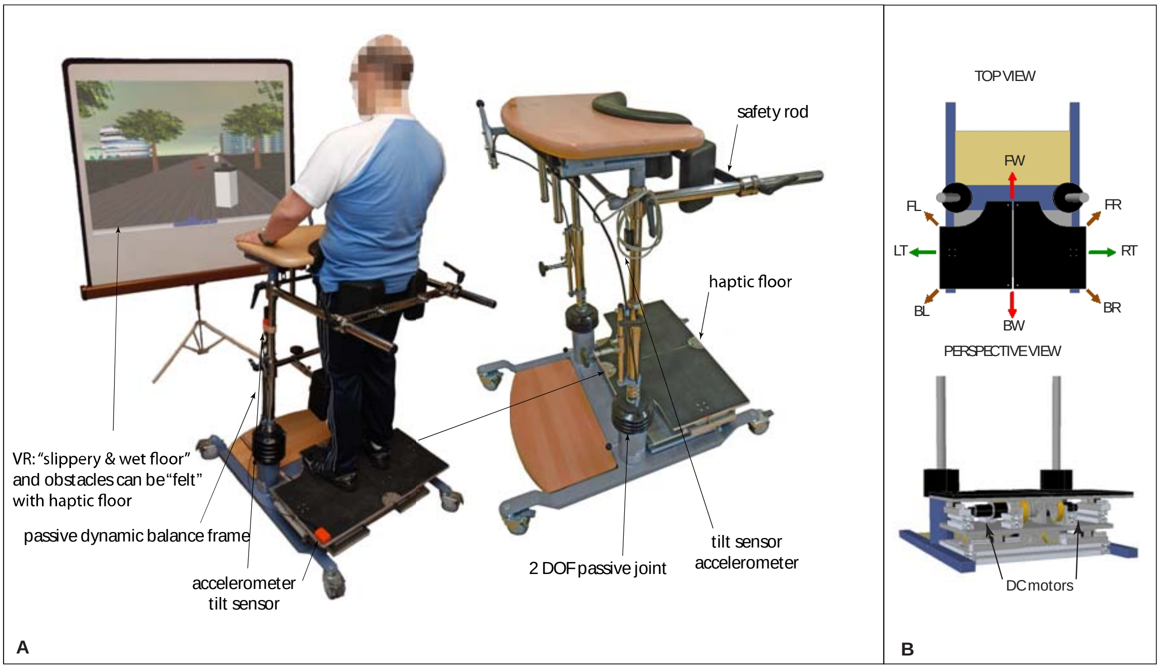

Figure 1. *Haptic floor enables better interaction with task for virtual reality supported balance training (Cikajlo et al, 2011). At collision with the virtual object or on slippery floor (**A**) the haptic plates suddenly moves in the opposite direction, generating a postural perturbation (**B**).*

Two control loops were designed to control the haptic floor. The outer control loop interacted with the VR world; the collision took place and according to the impact speed the amplitude (reference position) for haptic floor displacement was calculated and sent over TCP/IP to the RT. The inner control loop in RT comprised a PID controller. Ziegler- Nichols tuning method was applied to set the PID. Optional proportional gain (P) and derivative time set up in the way that step response would have minimal (<10%) overshoot and the response would be quick enough (>60% of the amplitude in <500ms, Loram et al, 2006). The integral windup was overcome by setting the integral component to the P/8.

2.2 *Subject and protocol*

A patient of University rehabilitation hospital (hemiparesis l. sin., F, age 55 years, 80 kg, 167 cm, 5 months after stroke, no neglect, MMSE: 27/30.) participated in the short-term VR supported balance training. Before VR supported balance training (VRBT), after 3 weeks and the follow up after 2 weeks the clinical tests Timed Up&Go (TUG), 10m walk test (10MWT), standing on healthy extremity (SHE) and Berg Balance Scale (BBS) were carried out. The VRBT protocol (Cikajlo et al, 2012) consisted of 3 x 5 min. of active balance training with resting time around 1 min between the sessions for 3 weeks in hospital environment and additional 2 weeks in smart-home environment (Smart Home Iris, www.dom-iris.si/en/).

After the first 3 weeks of VRBT we added a difficulty level upgrade with haptic floor. The subject "moved" forward/backward in the VR environment by leaning in anterior/posterior direction and turned by transferring the load to the opposite leg and tilting the whole body/frame left or right. When the subject hit the virtual object, the collision was detected. According to the speed and angle of impact the reference direction, speed and position of the haptic floor were calculated.

2.2 *Postural response assessment*

The haptic floor was designed to generate a step response at the time of collision with virtual object and thus present an interaction with the VR environment. Between the onset of collision and conscious postural control (< 300 ms) the subject's unconscious postural response was expected. The response was assessed by tilt and acceleration sensor mounted on the BTF. Gravitational and rotational components were subtracted from the measured acceleration. Further on, the signal in time & frequency space provided enough information to evaluate the postural response (Cikajlo et al 2009). However, we also considered that the haptic floor stopped and returned to the initial position (vertical posture) without generating any postural perturbation due to the smooth control with high damping.

3. RESULTS

Table 1. *The subject's clinical status rapidly improved in the first 3 weeks of VRBT.*

	before VRBT	after VRBT	follow up
BBS	47	49	52
TUG	23,3	18,0	19,0
10MWT	17,1	15,7	13,0
SHE	8,8	22,3	15,7

The subject has also improved the VRBT game score (mean task time from 93,0s to 42,8s and number of collisions from 12 to 5) and after the rehabilitation was using a single crutch only.

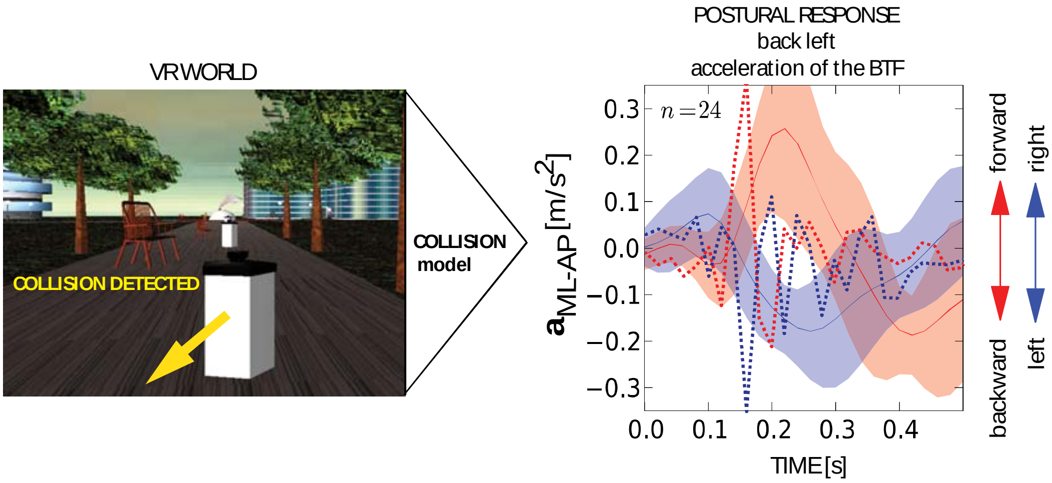

Figure 2. *The collision within the VR task resulted in the haptic information and the subject "felt" the impact. At the same time the postural response was assessed and compared with normative (shaded) assessed in neuromuscular intact subjects (Cikajlo et al 2011).*

4. DISCUSSION

The outcomes demonstrated that VR supported balance training had significant impact on the improvement of subject's clinical score. Similar results (Cikajlo et al 2012) proved that VR balance training can be as effective as conventional in clinical environment, but require less physical effort. Additional haptic information in general increases the perception of the task and enables a better cooperation between the robot and the human (Schmidt et al 2005). The robot can adapt the level of support and thus influence on the difficulty level of the goal based task. Hereby the collision or slippery floor required postural responses that not only increased the difficulty level, but also generated expected and unexpected postural perturbations. Thus we monitored the changes in postural responses (Pailex et al 2005) by recalculated accelerations in

anterior/posterior or medial/lateral direction and compared them with the normative in neuromuscular intact subjects. In most cases the subject's demonstrated premature actions and higher frequency movement at stabilisation (Fig. 2).

5. CONCLUSIONS

The goal based task in virtual environment motivated the subject who »forgot« to pay attention to his/her impairment. Thus more weight was transferred to the impaired lower limb. This was also one of major goals of balance training. Besides, the haptic feedback at the collision with the virtual objects also presented a postural perturbation. The subject's postural response was examined and evaluated. However, the major advantage of the haptic floor may be the assessment of postural responses during balance training. We came to the conclusion that the proposed system enable improved gradual increase of the task‘s difficulty level by adding haptic floor (Bisson et al 2007) and objective evaluation of postural responses (Cikajlo et al, 2009). Such enhancements to the VR based targeted tasks may besides balance training also enable improvement of postural responses (Marigold et al, 2005).The differences in postural strategies between postural responses with w/o VR and/or haptic feedback will be also further examined with electromyography and assessment of the centre of pressure.

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Interactive expressive virtual characters: challenges for conducting experimental studies about multimodal social interaction

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ABSTRACT

Advanced studies about social interaction address several challenges of virtual character research. In this paper, we focus on the two following capacities of virtual characters that are the focus of research in human-computer interaction and affective computing research: 1) real-time social interaction, and 2) multimodal expression of social signals. We explain the current challenges with respect to these two capacities and survey how some of them are used in experimental studies with users having Autism Spectrum Disorders (ASD).

1. INTRODUCTION

Interactive virtual characters are expected to lead to an intuitive interaction via multiple communicative functions, such as the expression of social signals via their facial expressions, speech and postures. These characters are often used as tools for conducting experimental studies on the way users perceive facial expressions of emotions. Multiple studies make use of canned animations of non-interactive virtual characters and ask subjects to report how they perceive the virtual character.

Research related to the dynamic generation of virtual agents' nonverbal behaviors stresses the importance of defining their temporal coordination with speech-based communication. One challenge for virtual agents platforms is to control very precisely the synchronization of communication channels (Gratch et al, 2002). In terms of software architecture, this implies simultaneous generation of these various communication channels from a unique representation (e.g. facial expressions should not be derived from the speech content but must be generated simultaneously). BEAT (Behavior Expression Animation Toolkit (Cassell et al. 2001)) is an example of a framework allowing the automatic generation of animations synchronizing speech synthesis, voice intonation, eyebrow movements, gaze direction, and hand gestures. From a functional standpoint (Scherer, 1980), facial expressions can take on semantic (e.g. to emphasize or substitute for a word), syntactic (e.g. nodding, raising eyebrows to emphasize parts of the speech flow), dialogic (e.g. gazes to regulate speech turns) or pragmatic (e.g. expressing the speaker's personality, emotions or attitudes) functions in a conversation. Rules for coordination of facial expression with speech depend on these functions (Krahmer and Swerts, 2009).

Anthropomorphic virtual characters are also being used in conjunction with eye-tracking technology to study social gaze in humans (Wilms et al., 2010) and to train children with ASD (Lahiri et al, 2011). Eyetrackers enable to control on-line the gaze direction of users and to change correspondingly the displayed information.

Several studies in the field of affective computing use virtual characters and a categorical approach to emotion in which a single expression of an emotion category, such as anger, is displayed in a single modality (e.g. facial expression). Some cognitive theories of emotion suggest a more complex dynamics in the emotional process and the corresponding display of facial expressions. For example, the Component Process Model suggests that current events are appraised according to a sequential flow of criteria and that corresponding facial signs are displayed sequentially (Scherer 2010). The MARC platform features a model

of appraisal adapted from this Component Process Model (Courgeon et al. 2008). Facial signs of appraisal are displayed during a real-time interactive game with the users.

Furthermore, virtual characters need to be able to express emotions in several modalities in a coordinated fashion. For example, facial expressions need to be coordinated with speech, lip-sync and bodily expressions during congruent and incongruent combinations (de Gelder et al. in Press).

The goal of this future vision paper is to survey the current challenges for designing advanced interactive virtual characters endowed with social interaction capabilities and their current and future application with users with ASD for experimental studies about social interaction.

2. METHODS AND RESULTS

In this paper, we argue in favour of using an empirical methodology based on series of experimental designs implemented with groups of typical participants and participants having cognitive disabilities. This scaffolding process enables validating hypotheses regarding human-computer interaction that are instrumental in designing appropriate software for users with disabilities. Although it requires conducting several experiments prior to the development of the proper training application used for treatment and its underlying interactive model, it seems useful to avoid software design premises based on typical populations, but that would prove inappropriate for autism (Grynszpan et al., 2007).

We hereafter illustrate this approach using examples of such experimental series.

2.1 Perception of the coordination between speech and facial expressions

We conducted an empirical study seeking to explore the influence of the temporal coordination between speech and facial expressions of emotions on the perception of these multimodal expression by users (measuring their performance in this task, the perceived realism of behavior, and user preferences) (Buisine et al. 2010). We generated five different conditions of temporal coordination between facial expression of a virtual character and speech: facial expression displayed before a speech utterance, at the beginning of the utterance, throughout, at the end of, or following the utterance. Subjects recognized emotions most efficiently when facial expressions were displayed at the end of the spoken sentence. However, the combination users viewed as most realistic, preferred over others, was the display of the facial expression throughout speech utterance.

These results yielded graphic design guidelines for developing expressive virtual humans used for training social dialog understanding in ASD. Considering the outcomes for typical individuals, we reasoned that multimodal expression of emotion would be optimized when the facial expression was displayed throughout speech utterance and remained after it ended. Given difficulties in ASD regarding emotion recognition, this temporal pattern was thought to most likely enhance their ability to interact with the virtual character.

2.2 Perception of the coordination between speech and facial expressions

In a second study using a gaze-contingent graphic display, we developed a novel method for investigating social gaze during face-to-face encounters with a realistic virtual human that could both speak and produce facial expressions of emotions (Grynszpan et al., 2011). Experimentations carried out with 13 adults and adolescents having High Functioning Autism Spectrum Disorders (HFASD) provided evidence for alterations in the ability of individuals with HFASD to self-monitor their gaze in a social context (Grynszpan et al, 2012a,b). This empirical evaluation also suggested that, although the comprehension scores of participants with ASD were beneath those of matched typical participants, they were able to improve over the course of the experimental trials. Their performances appeared to be correlated with the time spent looking at the facial expressions when their visual field was restrained to a viewing window around their focal point using a gaze-contingent eye-tracking system. Those results support the use of human-computer interfaces that combined multimodal interactive characters with eye-tracking technology.

3. CONCLUSIONS

In order to set-up the experiments described above, our MARC platform was extended and applied to include advanced features about real-time social interaction and multimodal expression of emotions. We are also exploring the use of such technology with depressed patients and the MARC platform was already applied to social anxiety (Vanhala et al, 2012).

Our next step will be to use realistic expressive virtual characters to conduct additional experimental studies about other social interaction capacities related to joint attention, realism of appearance, and feeling of presence.

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Neurocognitive rehabilitation approach for cerebral palsy syndrome by using the rhythm-based tapping tool to extend fields of perception and motion

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ABSTRACT

We focus on the difficulty of children with cerebral palsy to perform not only motor skills but also cognitive tasks, and hypothesize that rhythm-based tapping tasks help to enhance abilities of motions and cognitions cooperatively, if a personally-tailored rhythm is provided. In the experiment with the prototype tapping device, we found that a misalignment of the pacemaker with the internally-comfortable tempo brings subjects a feeling of discomfort and declination of performance if the task is in a rushed condition. This result suggests that a self-motivated rhythm may be enhanced through synchrony with the external rhythm, while it is disturbed by a gap between internal and external rhythms. This is an important step towards developing a rhythm-based rehabilitation method and a design principle focusing on subjects' individual internal rhythms.

1. INTRODUCTION

Cerebral palsy (CP) is the most frequent physical disability, or disorder, that onsets mainly in childhood. Over the past four decades, the number of reported CP patients has remained constant at 2 to 3 per 1,000 live births in industrialized countries, with low fetal mortality [Molnar, 1991]. Treatment of CP is a lifelong process that requires the collaboration of medical professionals including physiotherapists, the affected children, and their families. This is a type of permanent disorder, but it is not unchanging in terms of the neuro-developmental aspect.

The CP patients have problems in muscle tone, movement, and motor skills, especially in the ability to move body parts in a coordinated and purposeful way. Some patients also exhibit deficits in other areas, such as vision, hearing, and speech and learning, raising concerns about impairment of intellectual development. In other words, those deficits are caused by large-scale damage in the brain. Physical therapy treatments by medical professionals largely contribute to reconstruction in motor skills, and the procedure is well investigated and adequately equipped to care for patients with brain damage. In adult cases, patients often remember previous experiences with physiotherapists and are prepared to do unpleasant activities for recovery. However, children's expectations of the physical therapy, even with well-equipped facilities, often do not coincide with reality, and unwillingness often results.

Recently, brain plasticity enhanced by awareness, attention and concentration is a focus in studies of recovery of brain function and clinical treatments of rehabilitation—so-called cognitive- or neurocognitive rehabilitation. The combination of physical therapy procedures and retention of cognitive process in thinking and awareness aims for development of effective strategies that will open a new door in treatments for child CP patients and their developmental difficulty.

We have been devoted to developing a robotic training support device [Fukudome and Wagatsuma, 2011; Wagatsuma et al., 2012], particularly focusing on the self-motivated rhythm in motions (Fig. 1). The central

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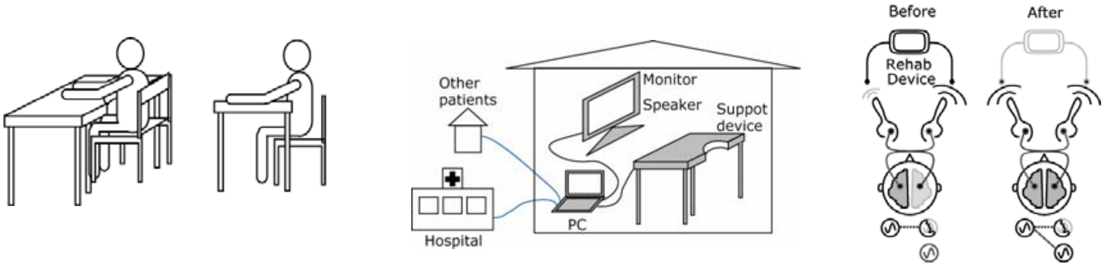
pattern generator (CPG) is well known as the common nervous mechanism embedded in the spinal cord of the animal body to control multiple limbs cooperatively and generate a wide variety of functional motor patterns, such as walking, stepping and running [Taga et al., 1991]. Synchronization between rhythmic movements of different limbs, which is caused by a collective neural activity in the brain, strongly governs the performance of both involuntary and voluntary movements (Fig. 1b) [Harken et al., 1985]. We hypothesized that necessary regeneration of the nervous system in the brain can be improved by the enhancement of an internal or self-motivated rhythm, which is easily reproduced by periodic and systematic movements.

In the present paper, we propose a concept of the rhythm-based rehabilitation method and explore the design principle focusing on subjects' individual internal rhythms. As a pilot experiment, we investigate the effect of the external sound that is provided by musical instruments with a certain tempo and evaluate the performance time and subjective feelings during the task. We hypothesize that a mismatch between the external rhythm and the internal rhythm (from synergy between bodily constraints and the nervous control) cause a feeling of discomfort and a declination in the performance.



(a) *(b)*

Figure 1. *A conceptualization of the robotic rehabilitation device. (a) Children with CP sit at the table and handle the device, which is connected to a portable PC for task presentation, recording of behavioral data and communicating with physiotherapists in the hospital. (b) A possible effect of rehabilitation through the rhythm-based device focusing on the internal rhythm generation* [Wagatsuma et al., 2012].

2. PROTOTYPE TAPPING DEVICE

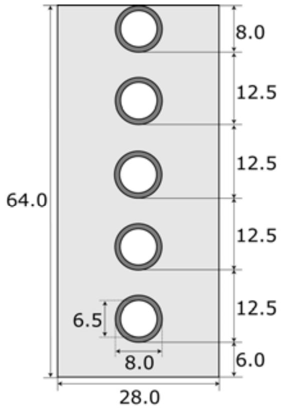
We designed a prototype of the tapping device for children with CP (Fig. 2). This device is inspired by the conventional reaching task for rehabilitation of hand movements, in which the children attempt to touch a far target position with their own hands, especially on the paralyzed side. This type of training is necessary to develop not only motor skills but also cognitive abilities, given that some children may have a deficit in a sense of the cognitive field, which may be caused by damage in the parietal lobe of the brain.

By using this device, memory tasks can be provided to set the flashing time to less than 100ms, which is considered to be an upper bound of the reaction time for normal subjects. Subjects had to memorize which button from five was flashed, as a short-term memory task. As they respond, the pushed button flashes again if it is the right choice. We set the memory and reaction task as shown in Fig. 3, and prepared a mechanical metronome (instead of musical instruments) in order to provide a simple external tempo to the subject during the task. As the task condition, we selected three tempos according to results of the preliminary experiment. Music therapy has a long history, and is ongoing on an empirical basis. Recently, a neuroscientific study has reported effects in the treatment of non-fluent aphasia [Tomaino, 2012], though it is still difficult to connect directly to physical therapy procedures. Here we simply used "Presto" as the fastest tempo, "Allegro" as the moderate and "Allegretto" as the slowest. The difference in interval time between the three tempos is approximately 100ms, which is similar to the flashing time and the fastest condition of the waiting time, w1. In the preliminary data, feelings of discomfort were reported when the external tempo was slightly slower (about 100ms) than the condition at which the subject exhibited the best performance. Thus, we investigated the correlation between the performance and arising unpleasant sensations.

3. EXPERIMENTAL RESULTS

According to the experimental design shown in Fig. 3, six normal subjects in their mid-twenties participated in the memory and reaction task. In the task, the next flashing position is determined by the random variable with uniform distribution from the four positions (minus the current position). Prior to the experiment, the researcher provided the subject with the following instructions: 1) let push the flashed button at a short

moment, 2) the next button will not flash until push the button, 3) task conditions and the sequential order are designed to be a set of [NS, PR, AR, ATT, PR, NS] and perform twice (Fig. 3) and 4) answer the questionnaire to ask the task difficulty in each tempo condition with 1-5 grades and feelings in the free-answer section. In this task, we do not provide any rewards and instructions to speed up operations, because we attempt to observe self-paced motion generations.



(a)

(b)

Figure 2. *The prototype of the tapping device with five palm-sized buttons. (a) Specifications and requirements for the device [cm]. This size reflects the physiotherapist's experience of rehabilitation for children with CP. (b) Our tapping device and its usage. This prototype is connected to the Arduino microprocessor board for controlling flashing positions and timing, and the PC monitors record the reaction time. The mechanical metronome is used for providing the external tempo.*

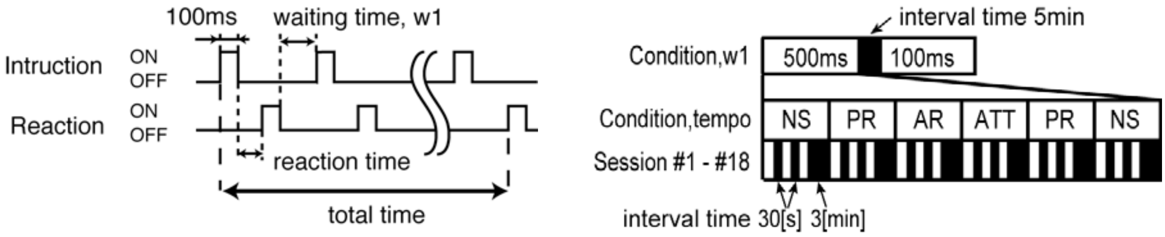


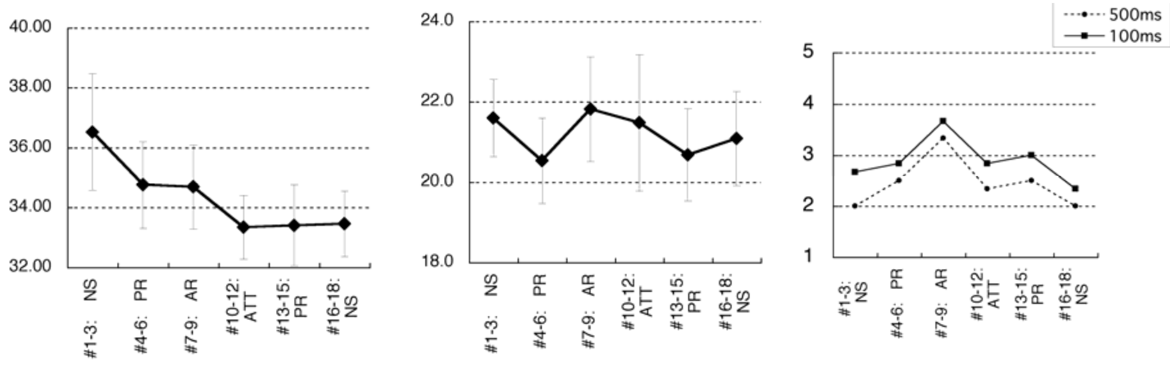
Figure 3. *Task design of the memory and reaction task. After each reaction, a new button is randomly selected and the light embedded in the button will flash after the waiting time,w1, which is prepared as 100ms and 500ms. NS denotes "No sound"; other abbreviations are shown in Table 1.*

Table 1. *External tempos provided in the memory and reaction task. The mechanical metronome (Fig. 2b) is used and set to one of the following three tempos. Note that beat per minute (bpm) can be converted to interval time [s]. We selected the three tempos according to results of the preliminary experiment.*

Presto (PR):	184 bpm	($\simeq$0.326 s)
Allegro (AR):	132 bpm	($\simeq$0.455 s)
Allegretto (ATT):	108 bpm	($\simeq$0.556 s)

Experimental results are shown in Fig. 4. In the easier condition ($w1 = 500\text{ms}$), the average declines according to the session number, which simply indicates a habituation or learning effect; the result is not influenced by the external tempo. There are identical "no-sound" condition (NS) at the beginning and the end; however, the total reaction time is significantly different between the two conditions. On the other hand, in the difficult condition ($w1 = 100\text{ms}$), there is no simple habituation and adaptation, and the two "Presto" conditions (PR), which are averages over sessions #4-6 and over sessions #13-15, demonstrated better performances than in the NS conditions. In the time series, this trend increases in the moderate condition (AR) and goes down again in the slow tempo condition (ATT). Interestingly, the score of how difficult the task condition is, which means a subjective feeling of easiness, represents a similar trend to the result with

$w1 = 100\text{ms}$. According to the detailed interview, most subjects answered that the AR condition is the most difficult case even in the easier condition ($w1 = 500\text{ms}$), showing a clear habituation.



(a) (b) (c)

Figure 4. *Experimental results of the memory and reaction task with and without sounds of the mechanical metronome. (a) Average data over all subjects in w1=500ms condition. (b) Average data over all subjects in w1=100ms condition. (c) Results of scores of the task difficulty (1: easy - 5: difficult) obtained from questionnaire sheets. Tasks were done separately in w1.*

4. CONCLUSIONS

We designed a prototype of a tapping device for children with CP. It is expected to be used instead of the conventional reaching task for rehabilitation of hand movements, especially on the paralyzed side, and extend to the rhythm-based rehabilitation tool. We found that a misalignment of the pacemaker with the personally comfortable tempo brings subjects a feeling of discomfort and declination of the performance if the task is in a rushed condition ($w1 = 100\text{ms}$). In addition, this result is consistent with the subjective feeling of how difficult the task is. This result suggests that a self-motivated rhythm is more disturbed by a slightly slow rhythm (about 100ms) than by the fastest one. Effectiveness of motor learning clearly appears in the condition of $w1 = 500\text{ms}$ (Fig. 4a), which occurs independent from the change of external tempo, even though the subjective feeling is the same as the 100ms condition. This fact suggests that motor learning or habituation is enhanced with/without external tempos in a range of the slow reaction. Therefore, a possible contribution of the external tempo is expected in the range of the limitations of the reaction time, approximately 0.1s, which might be related to the encoding time scale of the short-term memory. This is an important step towards developing a rhythm-based rehabilitation method and a design principle focusing on subjects' individual internal rhythms.

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Neurocognitive rehabilitation approach for cerebral palsy syndrome by using the rhythm-based tapping tool to extend fields of perception and motion

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ABSTRACT

We focus on the difficulty of children with cerebral palsy to perform not only motor skills but also cognitive tasks, and hypothesize that rhythm-based tapping tasks help to enhance abilities of motions and cognitions cooperatively, if a personally-tailored rhythm is provided. In the experiment with the prototype tapping device, we found that a misalignment of the pacemaker with the internally-comfortable tempo brings subjects a feeling of discomfort and declination of performance if the task is in a rushed condition. This result suggests that a self-motivated rhythm may be enhanced through synchrony with the external rhythm, while it is disturbed by a gap between internal and external rhythms. This is an important step towards developing a rhythm-based rehabilitation method and a design principle focusing on subjects' individual internal rhythms.

1. INTRODUCTION

Cerebral palsy (CP) is the most frequent physical disability, or disorder, that onsets mainly in childhood. Over the past four decades, the number of reported CP patients has remained constant at 2 to 3 per 1,000 live births in industrialized countries, with low fetal mortality [Molnar, 1991]. Treatment of CP is a lifelong process that requires the collaboration of medical professionals including physiotherapists, the affected children, and their families. This is a type of permanent disorder, but it is not unchanging in terms of the neuro-developmental aspect.

The CP patients have problems in muscle tone, movement, and motor skills, especially in the ability to move body parts in a coordinated and purposeful way. Some patients also exhibit deficits in other areas, such as vision, hearing, and speech and learning, raising concerns about impairment of intellectual development. In other words, those deficits are caused by large-scale damage in the brain. Physical therapy treatments by medical professionals largely contribute to reconstruction in motor skills, and the procedure is well investigated and adequately equipped to care for patients with brain damage. In adult cases, patients often remember previous experiences with physiotherapists and are prepared to do unpleasant activities for recovery. However, children's expectations of the physical therapy, even with well-equipped facilities, often do not coincide with reality, and unwillingness often results.

Recently, brain plasticity enhanced by awareness, attention and concentration is a focus in studies of recovery of brain function and clinical treatments of rehabilitation—so-called cognitive- or neurocognitive rehabilitation. The combination of physical therapy procedures and retention of cognitive process in thinking and awareness aims for development of effective strategies that will open a new door in treatments for child CP patients and their developmental difficulty.

We have been devoted to developing a robotic training support device [Fukudome and Wagatsuma, 2011; Wagatsuma et al., 2012], particularly focusing on the self-motivated rhythm in motions (Fig. 1). The central

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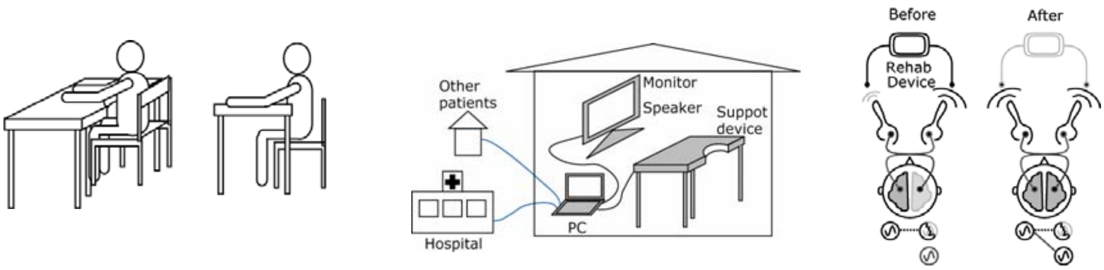
pattern generator (CPG) is well known as the common nervous mechanism embedded in the spinal cord of the animal body to control multiple limbs cooperatively and generate a wide variety of functional motor patterns, such as walking, stepping and running [Taga et al., 1991]. Synchronization between rhythmic movements of different limbs, which is caused by a collective neural activity in the brain, strongly governs the performance of both involuntary and voluntary movements (Fig. 1b) [Harken et al., 1985]. We hypothesized that necessary regeneration of the nervous system in the brain can be improved by the enhancement of an internal or self-motivated rhythm, which is easily reproduced by periodic and systematic movements.

In the present paper, we propose a concept of the rhythm-based rehabilitation method and explore the design principle focusing on subjects' individual internal rhythms. As a pilot experiment, we investigate the effect of the external sound that is provided by musical instruments with a certain tempo and evaluate the performance time and subjective feelings during the task. We hypothesize that a mismatch between the external rhythm and the internal rhythm (from synergy between bodily constraints and the nervous control) cause a feeling of discomfort and a declination in the performance.



(a) *(b)*

Figure 1. *A conceptualization of the robotic rehabilitation device. (a) Children with CP sit at the table and handle the device, which is connected to a portable PC for task presentation, recording of behavioral data and communicating with physiotherapists in the hospital. (b) A possible effect of rehabilitation through the rhythm-based device focusing on the internal rhythm generation* [Wagatsuma et al., 2012].

2. PROTOTYPE TAPPING DEVICE

We designed a prototype of the tapping device for children with CP (Fig. 2). This device is inspired by the conventional reaching task for rehabilitation of hand movements, in which the children attempt to touch a far target position with their own hands, especially on the paralyzed side. This type of training is necessary to develop not only motor skills but also cognitive abilities, given that some children may have a deficit in a sense of the cognitive field, which may be caused by damage in the parietal lobe of the brain.

By using this device, memory tasks can be provided to set the flashing time to less than 100ms, which is considered to be an upper bound of the reaction time for normal subjects. Subjects had to memorize which button from five was flashed, as a short-term memory task. As they respond, the pushed button flashes again if it is the right choice. We set the memory and reaction task as shown in Fig. 3, and prepared a mechanical metronome (instead of musical instruments) in order to provide a simple external tempo to the subject during the task. As the task condition, we selected three tempos according to results of the preliminary experiment. Music therapy has a long history, and is ongoing on an empirical basis. Recently, a neuroscientific study has reported effects in the treatment of non-fluent aphasia [Tomaino, 2012], though it is still difficult to connect directly to physical therapy procedures. Here we simply used "Presto" as the fastest tempo, "Allegro" as the moderate and "Allegretto" as the slowest. The difference in interval time between the three tempos is approximately 100ms, which is similar to the flashing time and the fastest condition of the waiting time, w1. In the preliminary data, feelings of discomfort were reported when the external tempo was slightly slower (about 100ms) than the condition at which the subject exhibited the best performance. Thus, we investigated the correlation between the performance and arising unpleasant sensations.

3. EXPERIMENTAL RESULTS

According to the experimental design shown in Fig. 3, six normal subjects in their mid-twenties participated in the memory and reaction task. In the task, the next flashing position is determined by the random variable with uniform distribution from the four positions (minus the current position). Prior to the experiment, the researcher provided the subject with the following instructions: 1) let push the flashed button at a short

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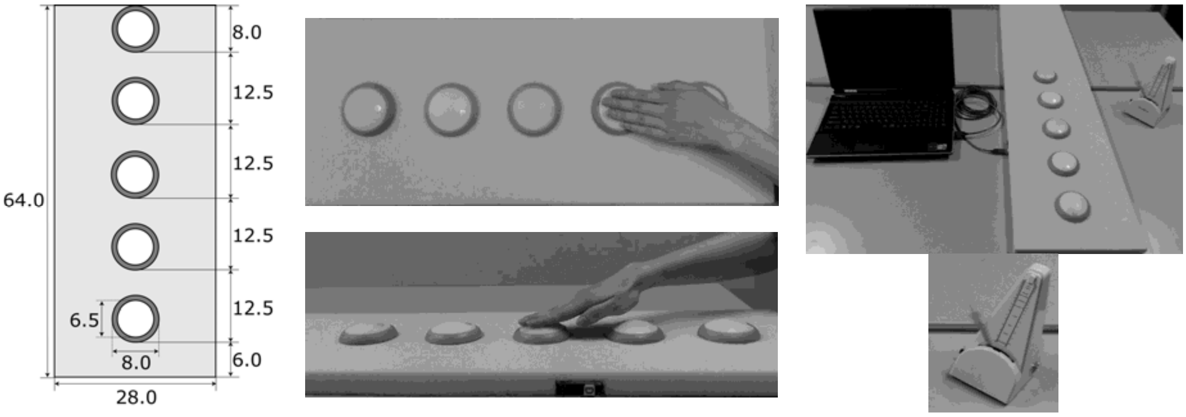
moment, 2) the next button will not flash until push the button, 3) task conditions and the sequential order are designed to be a set of [NS, PR, AR, ATT, PR, NS] and perform twice (Fig. 3) and 4) answer the questionnaire to ask the task difficulty in each tempo condition with 1-5 grades and feelings in the free-answer section. In this task, we do not provide any rewards and instructions to speed up operations, because we attempt to observe self-paced motion generations.



(a) *(b)*

Figure 2. *The prototype of the tapping device with five palm-sized buttons. (a) Specifications and requirements for the device [cm]. This size reflects the physiotherapist's experience of rehabilitation for children with CP. (b) Our tapping device and its usage. This prototype is connected to the Arduino microprocessor board for controlling flashing positions and timing, and the PC monitors record the reaction time. The mechanical metronome is used for providing the external tempo.*

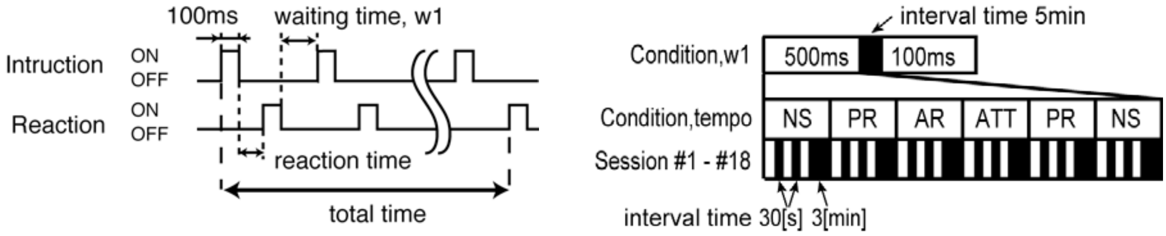


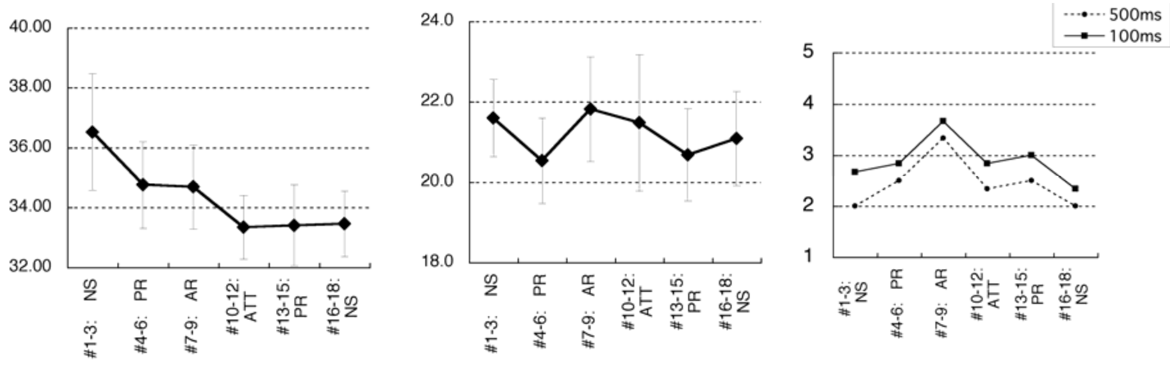
Figure 3. *Task design of the memory and reaction task. After each reaction, a new button is randomly selected and the light embedded in the button will flash after the waiting time,w1, which is prepared as 100ms and 500ms. NS denotes "No sound"; other abbreviations are shown in Table 1.*

Table 1. *External tempos provided in the memory and reaction task. The mechanical metronome (Fig. 2b) is used and set to one of the following three tempos. Note that beat per minute (bpm) can be converted to interval time [s]. We selected the three tempos according to results of the preliminary experiment.*

Presto (PR):	184 bpm	($\cong$0.326 s)
Allegro (AR):	132 bpm	($\cong$0.455 s)
Allegretto (ATT):	108 bpm	($\cong$0.556 s)

Experimental results are shown in Fig. 4. In the easier condition ($w1 = 500\text{ms}$), the average declines according to the session number, which simply indicates a habituation or learning effect; the result is not influenced by the external tempo. There are identical "no-sound" condition (NS) at the beginning and the end; however, the total reaction time is significantly different between the two conditions. On the other hand, in the difficult condition ($w1 = 100\text{ms}$), there is no simple habituation and adaptation, and the two "Presto" conditions (PR), which are averages over sessions #4-6 and over sessions #13-15, demonstrated better performances than in the NS conditions. In the time series, this trend increases in the moderate condition (AR) and goes down again in the slow tempo condition (ATT). Interestingly, the score of how difficult the task condition is, which means a subjective feeling of easiness, represents a similar trend to the result with

$w1 = 100\text{ms}$. According to the detailed interview, most subjects answered that the AR condition is the most difficult case even in the easier condition ($w1 = 500\text{ms}$), showing a clear habituation.



(a) (b) (c)

Figure 4. *Experimental results of the memory and reaction task with and without sounds of the mechanical metronome. (a) Average data over all subjects in w1=500ms condition. (b) Average data over all subjects in w1=100ms condition. (c) Results of scores of the task difficulty (1: easy - 5: difficult) obtained from questionnaire sheets. Tasks were done separately in w1.*

4. CONCLUSIONS

We designed a prototype of a tapping device for children with CP. It is expected to be used instead of the conventional reaching task for rehabilitation of hand movements, especially on the paralyzed side, and extend to the rhythm-based rehabilitation tool. We found that a misalignment of the pacemaker with the personally comfortable tempo brings subjects a feeling of discomfort and declination of the performance if the task is in a rushed condition ($w1 = 100\text{ms}$). In addition, this result is consistent with the subjective feeling of how difficult the task is. This result suggests that a self-motivated rhythm is more disturbed by a slightly slow rhythm (about 100ms) than by the fastest one. Effectiveness of motor learning clearly appears in the condition of $w1 = 500\text{ms}$ (Fig. 4a), which occurs independent from the change of external tempo, even though the subjective feeling is the same as the 100ms condition. This fact suggests that motor learning or habituation is enhanced with/without external tempos in a range of the slow reaction. Therefore, a possible contribution of the external tempo is expected in the range of the limitations of the reaction time, approximately 0.1s, which might be related to the encoding time scale of the short-term memory. This is an important step towards developing a rhythm-based rehabilitation method and a design principle focusing on subjects' individual internal rhythms.

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Virtual rehabilitation of the weigh bearing asymmetry in the sit-to-stand movement

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ABSTRACT

Weight bearing asymmetry is frequently used as a measure of impairment in balance control, and recovering symmetry in weight bearing is considered an imperative objective of rehabilitation. WBA rehabilitation is especially important for the sit-to-stand movement. Transition between sitting and standing, or vice versa, is one of the most mechanically demanding activity undertaken in daily life. In this contribution, we present a Virtual Rehabilitation system specifically designed for the recovery of the symmetry for this movement. The system has been designed with clinical specialists, and it presents very promising features such as the automatic adaptation to the patient. The paper is a work-in-progress that describes the system and presents the validation study that we will follow in a metropolitan hospital. Currently, we are enrolling patients, and the clinical specialists are very encouraged about the potential of the system.

1. INTRODUCTION

A wide variety of clinical population suffers Weight Bearing Asymmetry (WBA), as a consequence of their impairment. This problem especially affects patients with neurological impairments (Pai et al, 1994) and patients who have had lower limb musculoskeletal injuries (Talis et al, 2008). These patients tend to place more weight in the healthy limb, even when they have the capacity to balance more adequately the weigh distribution. This asymmetry is frequently associated with loss of postural control, for instance after a stroke (Bohannon, 1988) or due to pain in the injured limb (Hurwitz et al, 1999).

WBA is a potential source of deficit in balance control (Genthon and Rougier, 2005), and affects decisively patients, limiting their movements and increasing their risk of falling. Also, increasing loading in the healthy limb is associated with degenerative joint diseases in this limb. Thus, rehabilitation of WBA is critical to integrate patients in their activities of daily living (ADL).

One of the critical stages of the WBA rehabilitation is the sit-to-stand movement. Transitions between sitting and standing are fundamental for ADL in patients with neurological deficits (Cheng et al, 1998) and in patients with lower limb musculoskeletal injuries (Su et al, 1998).

On the other hand, in recent years there has been increasing research interest in the integration of video game technologies into motor rehabilitation programs. Specifically, different papers demonstrate the validity of Wii Balance Board® (WBB) based systems for rehabilitation and assessment (Gil-Gómez et al, 2011). The WBB is a device originally designed by Nintendo® for the Nintendo Wii® gaming system. It is an inexpensive, widely available wireless device, small size and weight. All these features facilitate their integration in the clinical routine. The WBB has four sensors, one in each corner, that allow to measure de center of pressure (COP) of the user. In (Clark et al, 2010) authors conclude that WBB provides comparable data to a laboratory-grade force platform.

Recently, many authors apply successfully the WBB to the WBA, but they are focused to the assessment of the WBA, not to the rehabilitation. In this way, Clark et al. (2011) demonstrates the reliability of the WBB for recording WBA and COP.

In this contribution we present a work-in-progress of a WBB based system specifically designed for the rehabilitation of the WBA during transitions between sitting and standing. The paper describes the system, that is completely developed, and the clinical trial designed to validate the system as a novel tool for WBA rehabilitation in the sit-to-stand movement. Currently we are selecting the patients for the clinical trial.

2. METHODS

2.1 System

In the design of the system, one of the most important decisions was whether to use one or two force platforms (WBB in our case). In this sense, some authors affirm that it is possible to obtain accurately WBA from a single force platform (Genthon et al, 2008), even for assessment. Other authors, as Clark et al. (2011), support the use of two force platforms to measure the force under each foot, improving the WBA accuracy.

In our case the system is designed for rehabilitation, not for patient evaluation, and then it is also necessary to consider the integration of the system in the daily clinical routine. Furthermore, more accuracy is usually needed in the calculation of the WBA in patient evaluation that in daily patient rehabilitation. Finally we integrate a single WBB in our system, with two footprints marked on it. With this setup we have enough accuracy for daily rehabilitation, and the integration in the daily clinical routine is very easy.

To evaluate the WBA of patients (before and after the validation study), we integrate a simple custom program that uses two WBB, one under each foot. We perform this setup for assessment following the conclusions of Clark et al. (2011), who demonstrate the reliability of a system based in this configuration.

2.1.1 Hardware. One of the advantages of the proposed system is its low cost and the easy integration of the system in the clinical environment. Also, all the hardware components are widely available.

As advanced, the system uses a WBB as the interaction device between patient and system. A conventional computer is also needed–no special high performance features are required- with Bluetooth, and a display device. As display device we recommend a 42”-47” LCD/LED TV, which would allow an easy integration in the environment with good visualization for the user. In our setup we are using a LCD/LED TV trolley floor stand with wheels at the bottom, which permits to move it around easily.

2.1.2 Software. The software of the system is a custom-designed program which utilizes the data sent by the WBB to calculate the WBA, and then it uses this information to perform the interaction. To calculate the WBA, the symmetry index (SI) is used; SI is explained in the Data Analysis section. The design of the software was carried out with the collaboration of clinical specialist in motor rehabilitation, to ensure the correct system approach from the clinical point of view.

Basically, the software is composed of three stages: initially a set of basic parameters is established by the specialist. This is followed by the main stage, which is a game played by the patient. Finally the system shows the main results of the game.

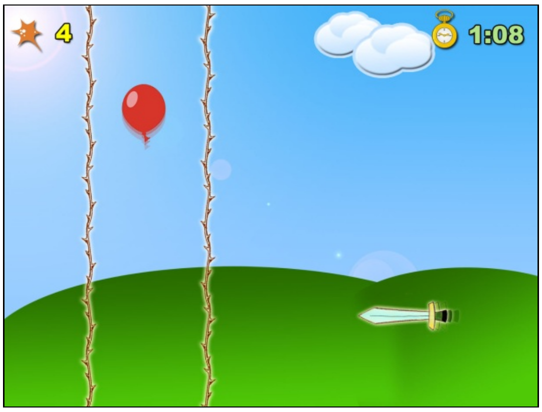

Figure 1. *Main stage of the game with patient standing up.*

As advanced, the main stage is a game, because one of the most important advantages of the virtual rehabilitation is the possibility of providing more entertaining rehabilitation. In this way we follow a game scheme, to motivate further the patient, increasing their adherence to the rehabilitation process. In the game, the patient controls a balloon that can move around the screen, see Fig. 1. When the patient rises from the chair, the balloon goes up until the top of the screen, and when the patient sits the balloon descends until the

bottom of the screen. In this vertical movement the globe is flanked by two sides with thorns. The balloon can also be moved laterally depending on the patient's SI, and then if the asymmetry is too high the balloon will touch one of the sides with thorns and it will explode. The patient does not see directly a SI score; he get SI feedback through the horizontal position of the balloon: the more balanced SI is, the balloon appears more centered between the two sides with thorns. The asymmetry tolerance of the system (the SI range in which the balloon does not explode) can be configured by the specialist or even can be adapted automatically by the system according to the patient.

In order to make the patient to stand or to sit, sharp elements appear during the game (darts, wasps, daggers, …) that move horizontally toward the balloon. These elements may emerge in two predetermined positions, up or down, coinciding with the vertical position of the balloon when the patient is standing or sitting. If one of the sharp elements touches the balloon it explodes.

All in all, the aim of the game is to keep the balloon intact as long as possible. During the game, the SI of the patient is registered in real time. The different events and parameters of the game are also registered, providing specialists data to analyze the evolution of the patient in their rehabilitation. It is necessary to emphasize that this data is very important, because this is information about the WBA patient during the sit-to-stand movement. Furthermore it is objective, non-dependent on the particular appreciation of a specialist.

Previously to the main stage, the specialist sets a number of parameters to customize the rehabilitation session. These parameters define variables such as session time, the speed of sharp elements and SI level allowed. This last parameter is very interesting, because it has the possibility of establishing an adaptive level: if the patient bursts the balloon quickly the system is progressively more permissive with the level of asymmetry of the patient; if the patient preserves the balloon for a long period, the system would became less permissive with the asymmetry of the patient. The aim of this adaptive level is to avoid the frustration of patients maintaining their motivation.

In the third and last stage, the system displays the result to the patient -the average survival time of each balloon-. With the results, the system provides visual and auditory reinforcement (confetti, applause, …).

2.2 Validation Study

As advanced in the introduction, this paper describes a work-in-progress. In this section we describe the criteria that we are following for the selection of the patients and other features that we consider for the validation study of the system.

2.2.1 Participants. We plan to validate the system with a minimum of forty patients, divided in two groups: control group and experimental group.

The inclusion criteria are: the ages of patients between 8 and 75 years old; patients can walk 10 meters indoors with or without technical orthopedic aids; Patients have WBA problems due to lower limb surgery and / or neurological deficits -SI over 20%, following Cheng et al. (1998) conclusions-.

The exclusion criteria are: patients whose visual or hearing impairment does not allow an appropriate interaction with the system; patients unable to follow instructions; patients with severe dementia; patients with cognitive impairment –Mini-Mental State Examination (Folstein1975) score under 24-; patients with unilateral neglect, aphasia, ataxia or any other cerebellar symptom. All patients will sign written informed consent prior to enrollment in the study.

2.2.2 Intervention. Patients will complete a total of thirty sessions: three sessions every week in a period of ten weeks. The control group will follow the traditional rehabilitation program during all the period. The experimental group will replace the corresponding time of the traditional rehabilitation with the proposed system. Every session will last for thirty minutes, including all the stages of the system. Depending on the patient and his condition at the time of the intervention, the specialist will divide a session in different sub-sessions, separating every sub-session by short breaks (from one to five minutes).

2.2.3 Data Analysis. For the data analysis we evaluate each patient twice: before the beginning of the validation study and immediately after. In each evaluation we obtain many different values, but we base our analysis especially in four values: SI during sit-to-stand movement, SI during stand-to-sit movement, time needed to stand up and time needed to sit down. The two last values are in seconds. The SI values are a percentage: the difference of weight bearing between both legs as a percentage of total body weight.

To obtain the SI in each evaluation we have developed a very simple application based on two WBB. In this case we use two WBB because we want to assess the WBA, and this setup is validated for this purpose (Clark et al, 2011). This application only requires the repetition of the sit-stand-sit transition as many times as defined. In our case, following the study of Christiansen et al. (2010) we use a total of five repetitions for

each patient. The final SI is the average of the SI of the five repetitions. For every patient we will measure their SI before the intervention period and after the intervention period.

3. CONCLUSIONS

Standing up and sitting down are among the most common activities in daily life. Thus the rehabilitation of the WBA in these movements is critical to prevent falls and enable the integration of patients in their ADL as soon as possible.

In this paper we present a system designed to rehabilitate these movements. The system has many potential advantages over the traditional rehabilitation methods. Once the parameters have been initially set up (a brief stage that last less than one minute for the specialist), the system can guide directly the patient in their rehabilitation session, without requiring specialist intervention. Moreover, the system is able to automatically adapt the difficulty of the task according to the characteristics of each patient. Due to the ludic approach proposed, the system increases the motivation of the patient, allowing the increase of the adherence to the rehabilitation process. The system records, automatically and in real time, the progression of patients, providing to the specialist objective feedback to evaluate their evolution.

We also present the validation study that we will follow for this system. This validation study will be conducted in a specialized service of a hospital. Currently, we are enrolling patients for the study.

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Reproduction of plosive sound vocalization by the talking robot based on the visual information

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http://www.eng.kagawa-u.ac.jp/~sawada/index_e.html

ABSTRACT

The authors are developing a vocalization training system for the auditory-impaired. The training system employs a talking robot which has mechanical organs like a human. With an adaptive learning strategy using an auditory feedback control, the robot autonomously learns the vocalization to speak like a human, and then reproduces the speech articulation from inputted vocal sounds. In the previous study, the training system for 5 Japanese vowels was constructed. The effectiveness was assessed by a training experiment conducted in Kagawa Prefectural School for the Deaf, and significant results were obtained. In the next step, the training system for consonant vocalization is studied. The plosive sounds such as /*p*/, /*t*/ and /*k*/ are produced by sudden opening and closing motions of a mouth, and it is not an easy task to reproduce the vocalization based on the auditory feedback learning. To solve this problem, visual information is employed to reproduce the plosive sound vocalization by the talking robot. In this study the learning method of the plosive sounds is introduced. The reproduced robotic vocalizations are evaluated by an experiment, and we validated that the robot successfully reproduced the vocalizations of the able-bodied.

1. INTRODUCTION

Speech plays an important role in daily communication. Only humans use words for verbal communication, although most animals have voices or vocal sounds. Vocal sounds are generated by the relevant operations of the vocal organs such as a lung, a trachea, vocal cords, a vocal tract, a tongue and muscles. The airflow from the lung causes the vocal cords vibration and generates a source sound, then the sound is led to a vocal tract to work as a sound filter as to form the spectrum envelope of a particular sound. The voice is at the same time transmitted to the human auditory system so that the vocal system is controlled for the stable vocalization. Various vocal sounds are generated by the complex articulations of vocal organs under the feedback control mechanisms using an auditory system. Any disability or injury to any part of the vocal organs or to the auditory system might cause an impediment in vocalization. People who have congenitally hearing impairments have difficulties in learning vocalization, since they are not able to listen to their own voice. In Japan, there are about 360,000 auditory impaired patients, and they are officially acknowledged by the government to receive medical supports. If you take into account the mild symptoms, the number of patients becomes approximately 6,000,000.

Auditory impaired patients usually receive a speech training assisted by speech therapists (ST) (Boothroyd, 1988), however many problems and difficulties are reported. For example, in the training, a patient is not able to observe his own vocal tract, nor recognize the complex articulations of vocal organs in the mouth. This causes the difficulty of recognizing the validity of his vocal articulation, and of evaluating the achievement of speech training, since he is not able to listen to his own voices. Auditory impaired children regularly receive the vocalization training in a deaf school, however training is interrupted by the school holidays, and they are likely to lose their speech skills during the recessions. The most serious problem is that the number of ST is not enough to give speech training to all the subjects with auditory impairment.

Several assistive devices and training systems for the auditory impaired patients have been reported so far Kitani et al., 2010). These training systems could show the vocalization differences between the able-bodied and the auditory impaired trainee by presenting visual information or vibratory sensations. Such systems,

however, are large and require technical knowledge and complex settings, which make it difficult for an individual patient to settle them at home. An assistive device or a simple training system that a patient regularly uses in daily speech training without special technical knowledge is strongly required.

The authors are developing a training system of speech articulation for auditory impaired people (Kitani et al., 2011). The system employs a talking robot constructed by mechanical vocal organs, and an artificial intelligence composed by a Kohonen's Self-organizing Map (SOM). The overview of the talking robot is shown in Figure 1. The talking robot autonomously associates the vocal tract shapes with the produced sounds by employing auditory feedback learning. The association is made by employing a dual-SOM consisting of two SOMs. By employing the talking robot, the training is realized by two different approaches. One is a training based on the hardware demonstration, which shows the speech articulation by the robotic motions, and the other is a software-based training, which presents the phonetic characteristics of generated voices. The effectiveness of the training system was examined in Kagawa Prefectural School for the Deaf as shown in Figure 2, and significant results were obtained.

In the previous system, the training of 5 Japanese vowels was mainly focused on. In the next step, the training system for consonant vocalization is studied. To construct the training system, the vocalizations of the consonant sounds have to be reproduced by the talking robot. The plosive sound such as /*p*/, /*t*/ and /*k*/ are generated by sudden opening and closing motions of a mouth, and it is not an easy task for the robot to reproduce the vocalization based on the auditory feedback learning, due to the short time vocal characteristics. To solve this problem, visual information is employed in this study, and the learning method of the plosive sounds is introduced. The reproduced robotic vocalizations are evaluated by an experiment, and we validate that the robot successfully reproduces the vocalizations of the able-bodied.

2. CONSTRUCTION OF THE TALKING ROBOT

The mechanical parts of the talking robot mainly consist of an air compressor, an artificial vocal cord, a resonance tube, a nasal cavity, and a microphone connected to a sound analyzer, which correspond to a lung, vocal cords, a vocal tract and the auditory system of a human, respectively. A resonance tube molded with a silicone rubber is settled at the sound outlet of the artificial vocal cord, and works as a resonator of a source sound to vocalize vowel and consonant sounds. To change the shape of artificial vocal tract, DC motors (motor #1 to #8) are settled at 8 positions from the intake side to outlet side.

3. REPRODUCTION OF PLOSIVE SOUNDS

Plosive sounds are produced by sudden opening and closing motion of the mouth. The time duration for the vocalization of /*k*/ is about 47[ms], /*t*/ for 24[ms] and /*p*/ for 21[ms], and the sounds have no periodic acoustic features, which results in the difficulty for the talking robot to reproduce the vocalization by the auditory feedback learning. In this study, the visual information is employed for the vocalization learning. An able-bodied subject makes vocalization in front of a camera mounted on the robot, and the cross-sectional area of the mouth is calculated by the image processing technique. The robot reproduces the plosive sounds by referring to the mouth shape.

Figure 3 presents the flow of the extraction of a mouth area using the image processing, together with an extraction result. A subject makes the vocalization of plosives sounds, and face images are obtained. In this study, three plosive sounds /*k*/, /*t*/ and /*p*/ are studied. A face region is extracted from the input image by using a classifier which employs Haar-like features (Viola and Jones, 2001). Based on the knowledge of facial parts, in which a mouth is located in the lower half of the face area, the mouth is extracted as a mouth image. Then, the mouth shape is obtained by the thresholding of color and brightness values.

Figure 1. *Overview of the talking robot.*

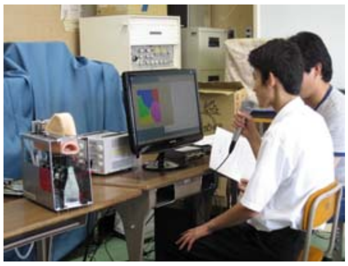

Figure 2. *Typical scene of vocalization training.*

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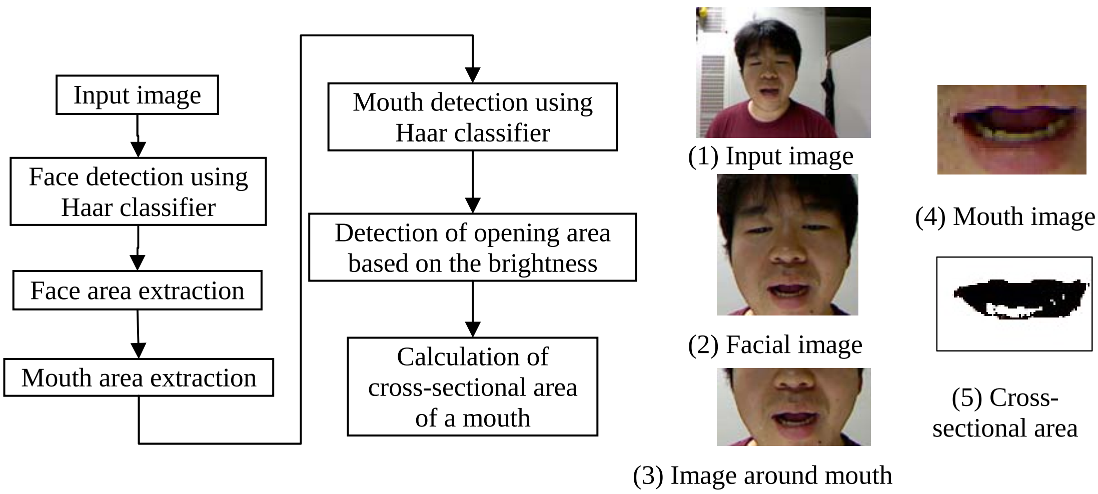
To reproduce the vocalization of plosive sounds by using the robot, the relation between the motor control commands and the cross-sectional area of the robotic mouth is studied. The stainless bar connected to the motor #1 which controls the opening and closing motion of the lips is moved from the upper-limit to the bottom-limit positions, by every 6[mm]. As shown in Figure 4, the cross-sectional area decreases linearly according to the closing motion of the mouth. The equation (1) is obtained by the regression, in which x indicates the cross-sectional area of the robotic mouth, and y indicates the height of the stainless bar from the original point.

$$y = -0.045\,x + 34.3 \tag{1}$$

In the next step, control commands for the motors from #2 to #8 are determined to reproduce inner motions of the mouth. In this study MR images obtained by one able-bodied subject are employed to determine the control commands. The vocal tract shapes of each plosive sound are measured by the MR images, and control commands for the robot are determined. Incidentally, as presented in Figure 5, the mouth shapes of plosive sounds are different with one another. The mouth shape of a subject is recognized by the image processing as described above, and the recognized plosive sound generates motor control commands for motors #1 to #8, so that the robot reproduces the sound.

Results of the reproductions of plosive sound vocalizations are shown in Figure 6. (a), (b) and (c) show the vocalization of /*p*/, /*k*/ and /*t*/, respectively. By comparing the robotic vocalizations with a human, the robot successfully reproduced the similar mouth shapes. The time durations of the produced plosive sounds are measured by using a high speed camera, and the result is shown in Figure 7. The robotic vocalization speeds are slow but the differences for three plosive sounds are well reproduced. To increase the articulatory speed of the robot, we are planning to employ the linear servo motors for the quick motions for the future study.



(a) Flow chart of image processing (b) Results of mouth extraction

Figure 3. *Extraction of opening area of a mouth.*

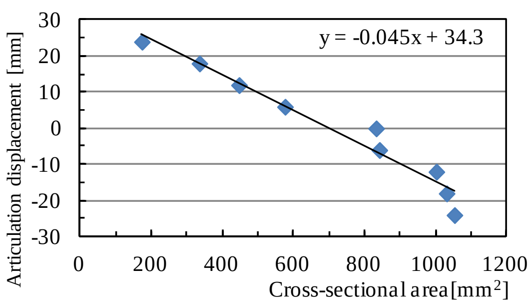


Figure 4. *Relation between mouth articulations and the cross-sectional area.*

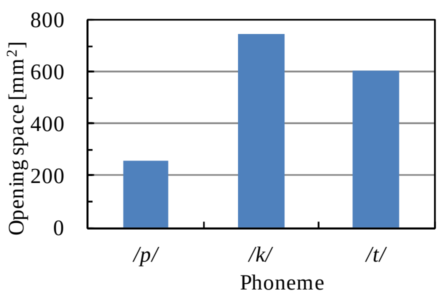


Figure 5. *Relation between three plosive consonants and the mouth opening areas.*

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The robotic vocalizations were successfully achieved by employing the visual information given by an able-bodied subject, and the robot reproduced the similar mouth shapes with a human. In the next step, we will construct a training system for all Japanese word vocalization, and conduct a training experiment in the school for the auditory-impaired to validate the effectiveness of the system.

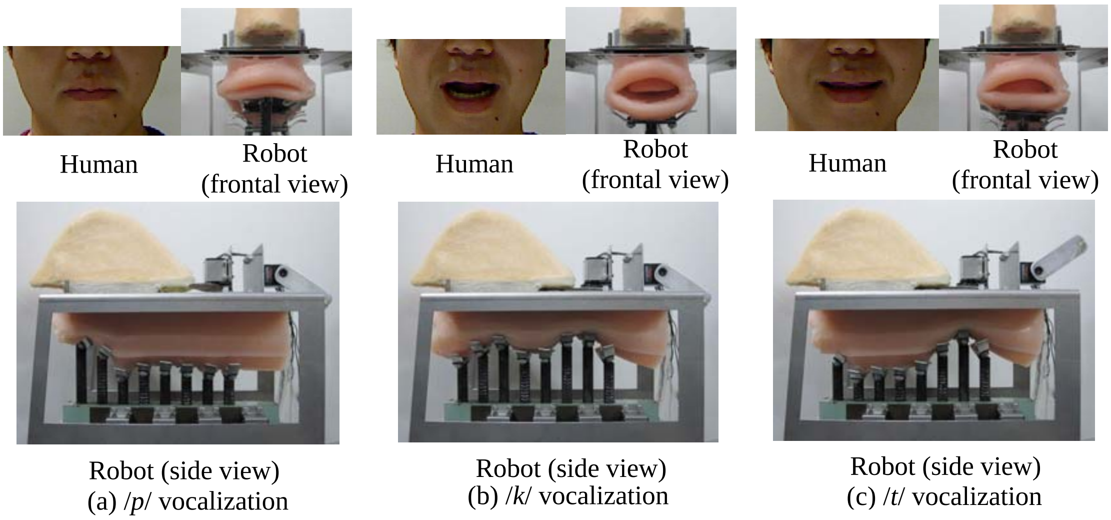

Figure 6. *Reproduction of three plosive sounds*

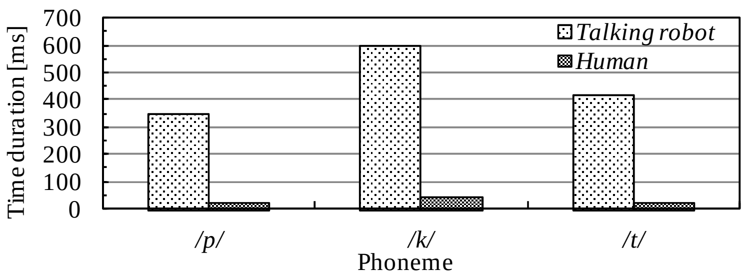

Figure 7. *Time duration of plosive sound vocalization.*

4. CONCLUSION

In this study the learning method of the plosive sounds for the talking robot was introduced. The robot successfully reproduced the plosive sound vocalizations based on the visual information obtained by an able-bodied subject. In the next step, the training system for all Japanese word vocalizations will be constructed. The training system visually instructs vocal articulations in a mouth by the interaction with the talking robot, and a trainee is able to recognize the articulatory differences by comparing his own vocalizations with robotic motions.

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Upper limb tracking using depth information for rehabilitative tangible tabletop systems

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ABSTRACT

The motor impairments that affect the upper limb, such as those following an acquired brain injury, are particularly disabling, since this body segment is involved in the majority of the activities of daily living. Virtual reality systems have been reported to stimulate the clinical effectiveness of the rehabilitative strategies, providing intensive and repetitive exercises in a motivating and controllable environment. The tracking of the upper limb movements in the real world is a challenging task that has traditionally involved different tracking systems. The use of depth sensors can provide a non-invasive solution that can be integrated in tabletop systems.

1. INTRODUCTION

Acquired brain in jury (ABI) can cause a wide combination of impairments affecting motor, cognitive and psychosocial skills. The motor complications that involve the upper extremities are among the most disabling impairments and can difficult, and even prevent, the performance of the activities of daily living (ADL). The traditional rehabilitative strategies focus on the restoration and compensation of the lost functionality through conventional physical and occupational therapy (World Health organization, 2006). In the last years there are an increasing number of systems that use the benefits of new technologies to assist patients and therapists in this complex task. Most of these systems exploit virtual reality technology to create controllable and safe environments where the patients are immersed to perform task-oriented exercises (Henderson et al, 2007).

Many of the virtual rehabilitation (VRHB) systems use robotic devices as therapeutic tools that either help the patients or impede them to perform the required movements (Volpe et al, 2009; Gijbels et al, 2011). Other systems require the patients to interact through movements of their upper extremities on a table (Cameirao et al, 2010; Kuttuva et al, 2006). The surface is used to physically support the arms while the tracking is carried out by other systems (optical, electromagnetic, etc.). Recently, the multitouch devices have been considered with rehabilitative goals. The patients are allowed to interact with the virtual environment through finger touches (Annett et al, 2009) or even grasping tangible objects, that are tracked through optical systems from an upper (Numford et al, 2010) or a lower plane of the table (Dunne et al, 2010). These tracking systems determine the position where the finger makes contact with the surface or the position of the tangible object on the surface but cannot discern the movements of the body segments and joints that take part in the natural movements of the upper limb.

However, even the simplest movements of the upper extremities are extremely complex and specific. The implication of shoulder, arm and hand requires the synchronized execution of appropriate motor patterns and the accurate performance of multiarticular dynamics (Kalaska et al, 1992), which cannot be estimated with the aforementioned tracking strategies.

The objective of the work presented here was to design a new interface based on depth information that could be able to track accurately the movements of the hemiparetic upper extremities and that could be integrated in a tangible tabletop rehabilitation system.

2. MATERIALS

2.1 Hardware

The hardware components of the tabletop system consist of a table, a standard computer, a projector, and a depth sensor (DS). In the prototype described here a Kinect sensor is used (Microsoft, 2012). The projector and the sensor are fixed in an upper plane of the table oriented to its surface (Figure 1). This way, the projector displays the virtual environment on the table and the patients interact within it through movements of their own extremities.

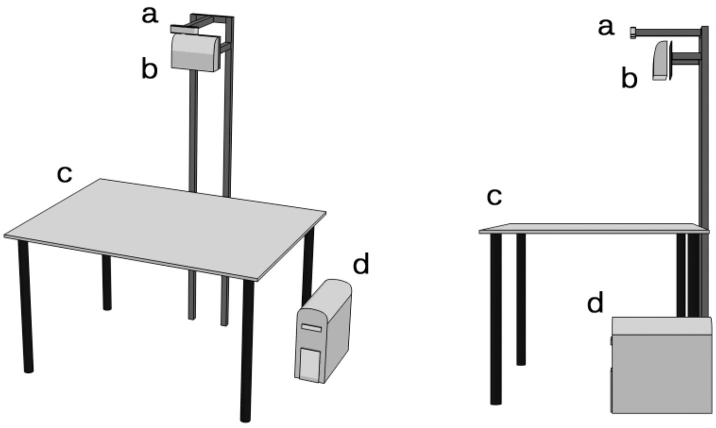

Figure 1. *Hardware components of the system: a) depth sensor; b) projector; c) table; and d) standard computer.*

The DS emits a pattern of infrared rays with different intensity and thickness values over the scene and detects the backscattering rays with a monochrome CMOS sensor that is 5cm displaced from the emitter. The DS estimates images of size 640x480 with 11 bits of sensitivity (2048 possible grey values to describe the distance of the object to the sensor) at a frame rate of 30 fps (Figure 2). The recommended working range of the DS varies from 1.2m to 3.5m but the minimum distance can be reduced to 0.7m, as set in our tabletop system. Since the field of view of the DS is 57º in the horizontal plane and 43º in the vertical plane, the sensor can cover an area of 87cmx67cm over the surface, which leads to a spatial resolution of 1.36mmx1.39mm per pixel.

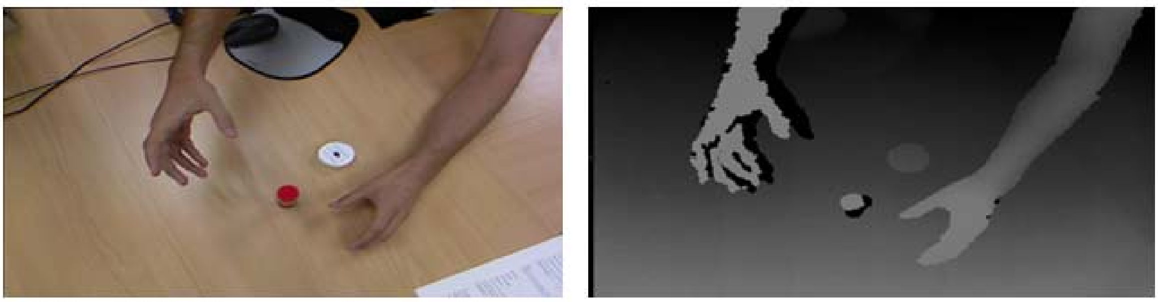

Figure 2. *Comparison of a scene acquired by a RGB camera and by a depth sensor.*

2.1 Software

To make the tracking possible, its general workflow is divided into 3 main steps: workspace estimation (to estimate the space area that is part of the workspace), calibration (to estimate the depth values for which the segments make contact with the working plane), and tracking (to process the 3D positions of the interesting segments). Each exercise requires a specific calibration to define the position in which the implied segments and external objects (if needed) are in contact with the surface (first and second columns of Figure 3). Generally, the segments and objects are estimated using the depth information and their skeletons and their mass centers are defined using the distance matrix of the segments. In those exercises which mostly imply the metacarpophalangeal and interphalangeal joints, a special effort is done to track the fingers. In this case, the hand is segmented likewise and then the convex hull is applied to estimate the fingers.

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With the described tracking capabilities it becomes possible to design a set of exercises as a part of a rehabilitation protocol for hemiparetic patients with acquired brain injury taking into account the brain plasticity and motor learning principles (Krakauer, 2006). The exercises cover movements that were likely to belong to the motor repertory of the patients previously to the injury and aim to maximize the correlation of the virtual tasks with the real tasks of the ADL. For instance, the objectives of some exercises are to dial a telephone number, to cook, to knock a door, and to play a keyboard (Figure 3, rows 1 to 4, respectively).

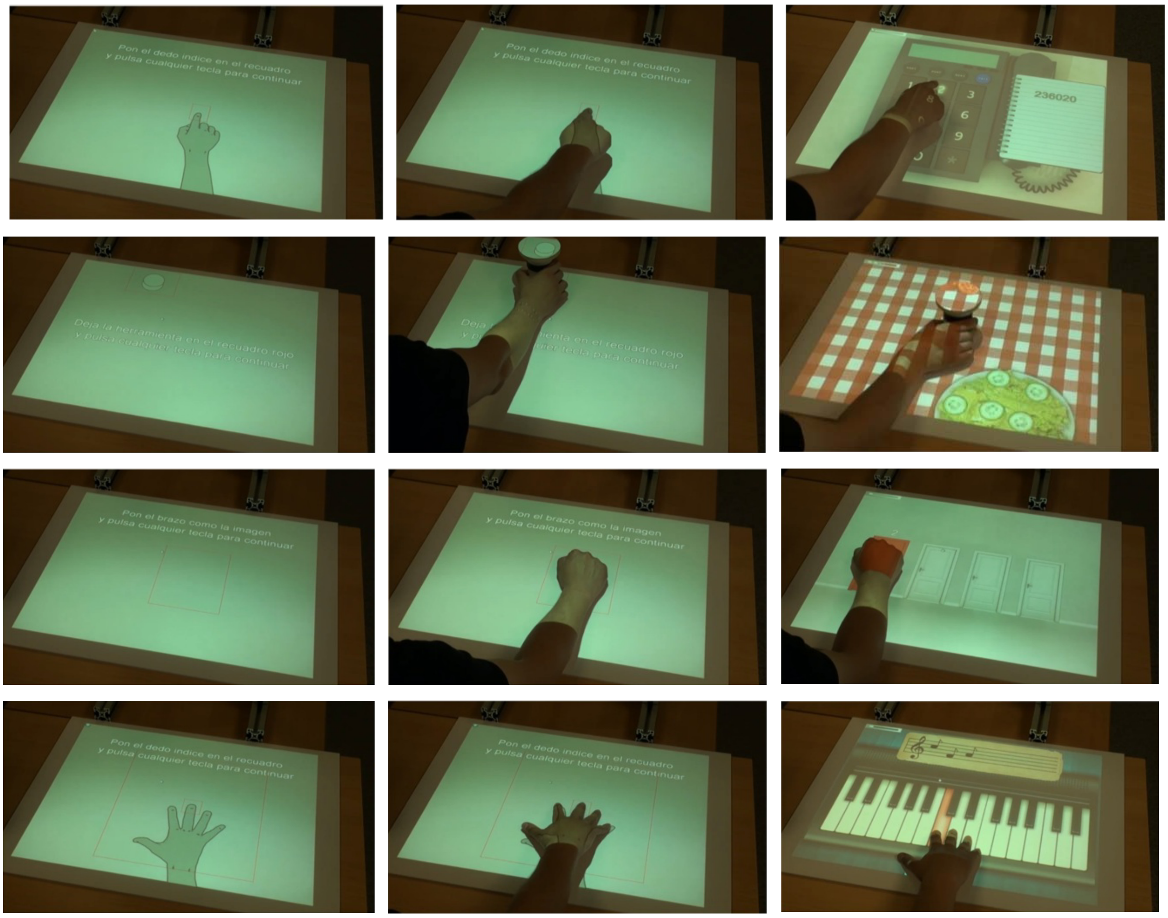

Figure 3. *Examples of exercises.*

3. CONCLUSIONS

The presented work describes a tracking solution for the upper extremities using a depth sensor that provides accurate tracking of the main segments and joints of the arm, including the movement of the fingers.

The tracking is especially interesting for being used in tabletop frameworks. This way, the patients can lean their arms on a table, which is especially interesting for those who cannot hold their arms against gravity. The tracking is not invasive since it does not require any device or sensor to be attached to the arms and it allows the free movement of the extremity. In addition, the tracking makes possible the manipulation of tangible objects with different shapes and sizes, even detecting grasps and pincer grips, which are recurrent in the ADL. However, the optical nature of the DS prevents the therapists from assisting the movement, since their arms can enter in the tracking area and mislead the tracking system (the disambiguation of the extremities of both subjects is not obvious) or occlude the patient’s extremity. In addition, the DS is inevitably subject to noise that can induce a ‘jitter-like’ effect that distorts all the estimations.

The described tracking solution has been integrated in an upper limb rehabilitation system for hemiparetic ABI patients. A set of exercises has been developed considering the motor learning principles and maximizing the correspondence with the ADL. The exercises cover a wide range of movements commonly trained in conventional therapy programs: flexion and extension of the wrist or of the metacarpophalangeal joint, grasping, tapping, etc. To prove the clinical effectiveness of the tabletop system in the rehabilitation of

ABI patients, a randomized controlled trial is being carried out in the neurorehabilitation service of a large metropolitan hospital.

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Convergent validation of a virtual reality-based street crossing with neuropsychological tests in neglected and non-neglected stroke patients

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ABSTRACT

Unilateral spatial neglect is one of the most common and disabling impairments of stroke. The assessment of this deficit is carried out with paper and pencil tasks that can lack correspondence to everyday activities. Virtual reality can recreate realistic but safe environments that allow the therapists to study how the patients would react in real life situations. This paper presents a virtual street-crossing system that immerses the participants in a recreated street where they are asked to navigate safely. The presented study with chronic stroke patients showed remarkable correlations of the performing variables of the system with standard cognitive scales, which suggests that virtual reality systems can evidence alterations in cognitive skills, such as neglect.

1. INTRODUCTION

Unilateral spatial neglect (USN) is a common consequence of brain injury. It is one of the most disabling impairments since it affects the perception of the stimuli of part of the environment, which directly interferes on the performance of the activities of daily living (ADL) (Allegri, 2000). However, USN is traditionally diagnosed through paper and pencil tasks that are rarely associated with functional activities.

The use of virtual reality (VR) technology in the rehabilitation domain has given rise to several systems related with USN (Tsirlin et al, 2009). VR can immerse patients in realistic scenarios and monitor their performance, and therefore allow therapists to discern how they would react under real circumstances. Most of the VR systems are oriented to help the therapists in the assessment of the impairment. These systems present a specific virtual scenario and track the patients' performance while carrying out some actions (Kim et al, 2004; Tanaka et al, 2005; Broeren et al, 2007). Other systems provide rehabilitative exercises to diminish the effects of the neglect (Smith et al, 2007; Castiello et al, 2004). Those systems that recreate ecological and dangerous activities are especially interesting, since USN can prevent their safe execution in real life. The street-crossing task represents a good example of those activities. As a proof, this task has been previously used with successful results (Katz et al, 2005).

The objective of the presented work was to design a virtual street crossing system and to analyze its convergent validity with standard clinical scales used to assess unilateral spatial neglect and other cognitive skills (Table 1) in stroke patients diagnosed with and without neglect.

2. METHODS

2.1 Participants

For this study, a sample of chronic stroke patients was recruited from the neurorehabilitation service of the Hospital NISA Valencia al Mar. Inclusion criteria were: 1) chronicity>6 months; 2) Mini-Mental State Examination>23 (Folstein et al, 1975). Exclusion criteria were: 1) severe aphasia (Mississippi Aphasia Screening Test comprehension index<45 (Nakase-Thompson et al, 2005)) or dementia; 2) visual or hearing

impairments that prevent the correct interaction with the system. The final sample of the study consisted of 32 chronic stroke patients with a mean age of 54.8±12.2 years (mean±std) and with a mean chronicity of 397.8±241.9 days (mean±std).

According the assessment through the conventional subtests of the Behavioral Inattention Test (BIT) (Hartman-Maeir and Katz, 1995), the sample was divided into two groups: neglected and non-neglected participants. 17 participants were diagnosed as neglected (BIT scores<129) and 15 as non-neglected.

2.2 Instrumentation

The VR system recreates a real scenario of the city of Valencia with a first person view. The virtual scenario covers an area that includes 2 two-way roads where different stimuli, such as cars, traffic lights, and simple lights and sounds, can be configured by the therapists to adjust different distractor levels according the attentional level of the participants (Figure 1).

Figure 1. *Comparison of the virtual (left images) and real (right images) world.*

The output of the VR systems consists of a 42” TV screen and a 2.1 sound system. The participants interact within the virtual environment by means of a joystick and a head tracking system. The joystick transfers translational displacements in discrete spatial directions, moving forwards and sideways, using a strafing technique. The head tracking system estimates the position of the head, although only the yaw rotations of the head are taken into account to change the yaw orientation of the camera view in the virtual environment. The head tracking is carried out by a NaturalPoint TrackIR™ system. The TrackIR™ is an optical tracking system that consists of an infrared optical camera which bounces an infrared light beam on the scene and a clip of reflective marks that reflect the light. The camera estimates the position of the clip from the reflections. The clip is mounted on a cap and can be easily worn (Figure 2).

2.3 Intervention

The study was carried out in a dedicated and controlled room of the neurorehabilitation service. The participants sat in front of the TV screen and held the joystick with their dexterous hand. In case of hemiparesis they used their unaffected hand. The participants were asked to perform twice the same task in the virtual system, which consisted of going from an origin point to an end point (supermarket) and then coming back. In each repetition, the participants were forced to cross the two-way roads 4 times (2 in each direction), avoiding the cars that could appear from the lateral sides. For this study, the time to complete the task and the number of accidents were registered. The task was considered uncompleted if the number of accidents was greater than 4. In addition to the VR outcomes, all the participants were assessed with a battery of scales taking into account different cognitive skills (Table 1).

Figure 2. *Hardware setting of the VR system. 1) TrackIR™ camera; 2) Clip of reflective marks; 3) Joystick.*

Table 1. *Cognitive assessment test battery.*

Behavioral inattention test (BIT)	Unilateral spatial neglect
Conner's performance test-II (CPT-II) (Conners et al, 2003)	Attention, vigilance, and impulsivity
Color trail making test part A and B (CTMT-A, CTMT-B) (Llorente et al, 2003)	Cognitive flexibility, mental processing speed, and visuomotor skills
Behavioral assessment of dysexecutive syndrome (Wilson et al, 1998)	
Zoo map test part 1 and 2 (BADS-ZMT-I and II)	Planning ability
Key search test (BADS-KST)	Problem solving

3. RESULTS

From the total sample, 14 non-neglected participants (93.3%) and only 3 neglected participants (17.6%) managed to fulfil the task. Focusing on the 17 patients that could finish the task, statistical analysis showed that participants without USN finished the task quicker and more safely than patients with USN (time to complete: $F=28.8$, $p<0.01$; number of accidents: $F=55.8$. $p<0.01$).

Besides that, the time to complete the task correlated with the CTMT-A ($r=0.75$, $p<0.01$), the CTMT-B ($r=0.55$, $p<0.01$), the BADS-KST ($r=-0.5$, $p<0.05$), the BADS-ZMT-1 ($r=0.6$, $p<0.01$) and the BADS-ZMT-2 ($r=-0.4$, $p<0.05$), and the hit rate ($r=0.6$, $p<0.05$) and the number of omissions ($r=0.6$, $p<0.01$) of the CPT-II. In addition, the number of accidents correlated with the BIT ($r=-0.7$, $p<0.01$), the BADS-KST ($r=-0.4$, $p<0.05$), the BADS-ZMT-1 ($r=-0.5$, $p<0.01$) and the BADS-ZMT-2 ($r=-0.3$, $p<0.05$).

4. DISCUSSION

The statistical analyses showed that the presence of USN dramatically affected the performance of the participants in the VR system. Most of the non-neglected participants not only finish the task but also achieved better scores in terms of speed and security. As expected in real conditions, neglected participants show worse performance. Consequently, the design of the system is coherent with the real world.

Regarding the relations of the VR outcomes with the neuropsychological tests, the time to complete the task correlated with those tests which take time measurements into account (the CTMT, BADS, and CPT) and did not correlate with the BIT. On the contrary, the numbers of accidents suffered in the VR session correlated with the BIT, which can show that the visual and perceptual skills required to safely carry out the virtual task are also involved in the BIT test to assess the USN. In addition, the requirements of higher executive functions (such as planning, multi-tasking, and problem solving) could explain the correlations of the number of accidents with the BADS scores.

In conclusion, the presented study with chronic stroke patients showed remarkable differences between the performance in the VR system of the neglected and non-neglected participants, and also showed correlations of the VR outcomes of the system with standard cognitive scales, which suggests that virtual reality systems can evidence alterations in cognitive skills, such as neglect, as previously reported (Tsirlin et al, 2009).

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Virtual 3D shape and orientation discrimination using point distance information

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ABSTRACT

Distance information is critical to our understanding of our surrounding environment, especially in virtual reality settings. Unfortunately, as we gage distance mainly visually, the blind are prevented from properly utilizing this parameter to formulate 3D cognitive maps and cognitive imagery of their surroundings. We show qualitatively that with no training it is possible for blind and blindfolded subjects to easily learn a simple transformation between virtual distance and sound, based on the concept of a virtual guide cane (paralleling in a virtual environment the "EyeCane", developed in our lab), enabling the discrimination of virtual 3D orientation and shapes using a standard mouse and audio-system.

1. INTRODUCTION

Understanding the distance between ourselves and the objects surrounding us is fundamental to our perception of our environment. It helps us locate objects, estimate their sizes, recognize them and the spatial relation between them, manipulate them and navigate to and between them. Our perception of these distances relies heavily on visual information (as can attest anyone who ever tried to find something in a dark room).

This reliance on visual information is exacerbated in virtual environments, which are becoming an increasingly larger part of our lives in fields ranging from education through navigation to games. While computer screens are flat 2D surfaces, the information conveyed within them often includes depth information, known as 2.5D. This feeling of depth is accomplished using a series of graphical visual cues, such as shading, which our visual system interprets as depth. As this information is visual, it is completely inaccessible to the blind, and usually very difficult for the visually impaired to interact with as well.

Enabling the blind to quickly and easily assess distance to virtual objects is especially important as virtual environments hold great potential for the blind, such as allowing them to safely pre-learn novel real environments before visiting them, when currently they are restricted to routes trained explicitly on a one-on-one basis with an instructor, limiting independence in every-day lives.

While many attempts have been made to create dedicated virtual environments for the blind, these environments suffer from two major problems. First, they rely on either a 3rd person map-like view from above (Feintuch 2006), or on simulating the white-cane within the environment (Lahav 2009), instead of allowing a more realistic egocentric 1st person or close-3rd person experience as most virtual environments offer and which is also easier for the blind to learn, since they use more egocentric-based spatial strategies than map-like ones. Second, they require heavily preprocessing for tagging various in-world objects with the meaningful descriptors these environments require, which renders most virtual worlds irrelevant.

Here we attempt to use a virtual version of a new technique from the real-world, a virtual cane known as the "EyeCane" (Maidenbaum 2011), in order to avoid these problems. The "EyeCane" measures the real-world distance between the device and the object it is pointed at using infra-red emissions and produces a corresponding auditory signal. As point distance information can be calculated from any 3D Mesh, using a virtual parallel of such a method is easy to implement in any virtual environment, which is a significant step in making nearly all virtual environments more accessible. Additionally, success under these conditions would show that it can potentially be achieved in the real world as well, showing the potential for real-world narrow-beamed virtual canes for enabling such recognition.

As a first step we tested the ability of our subjects to use this approach to recognize simple virtual shapes within a virtual environment. Previous successful work using other methods focused on the ability of the blind to correctly discriminate between 2D shapes (Amedi 2007, Chen 2011), a task which we chose to repeat and begin from as a foundation for the next steps. We then tested this concept in two additional levels by having the subjects discriminate between the 3D orientation of rectangles and between various 3D shapes. This experiment was conducted with no training at all, to show the simplicity of the concept.

2. METHODS

2.1 The tasks

The experiment consisted of three tasks:

1. *2D shape recognition***.** Subjects were requested to identify and discriminate between 2D virtual shapes. Specifically, whether the virtual shape was a circle, square or triangle.
2. *3D rectangle orientation.* Subjects were requested to identify the orientation of the virtual rectangle and decide if the top end of the shape was oriented into the screen, parallel with the screen or out of the screen. An example of such 3D rectangles can be seen in fig 1b.
3. *3D shape recognition*. Subjects were requested to identify if the virtual shape was a sphere, a bowl, a half-cylinder or a pyramid. An example comparing the sphere and bowl is shown in in fig 1c.

Tasks 1 and 2 were given in a random order, but always preceded task 3. No training was given for any of the tasks, and thus subjects had to recognize the shapes throughout the trials and not simply discriminate between them. A yes/no feedback to their responses was given between trials.

Subjects were instructed to disregard time and scanning-path length and focus on correct identification. They were encouraged before the tasks to try and think of strategies to recognize the various shapes.

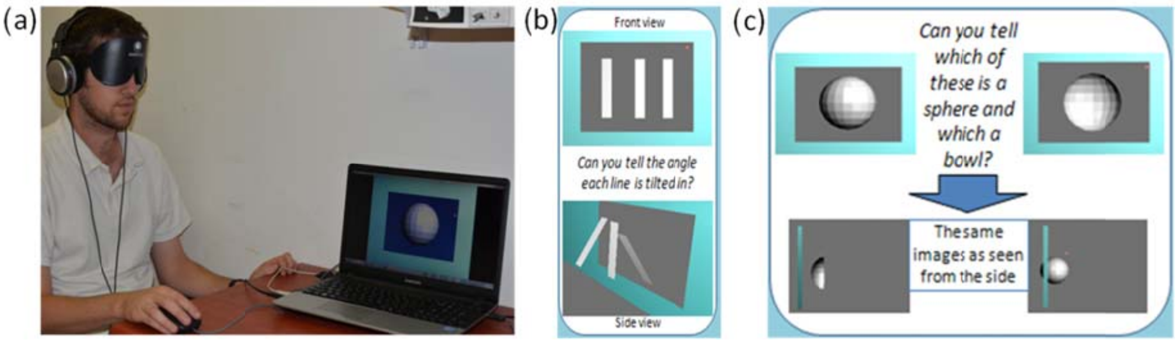

Figure 1. *(a) A blindfolded sighted user with the system. (b). Illustrates the 3D rectangle orientation task. In the upper panel are 3 rectangles, whose 3D orientation is undeterminable to the user visually. The lower panel illustrates the relative simplicity of this task when performed visually from a different angle. In the experiment only one rectangle was presented at a time. (c). Illustrates the 3D object recognition task. In the upper part are a concave bowl, and a convex ball. As in (a) the lower part illustrates the relative simplicity if performed visually from a different angle. While in (b) one could attempt to use slight visual cues such as shading to discern between them, the correct answer indicated by shading depends on the location of the light source. In the experiment only one shape was presented at a time.*

2.2 The software

We created dedicated virtual environments using Blender 2.49, and Blender-Python modules using python 2.6.2. Within these environments we used a Ray-Casting algorithm (which calculates the distance to the object the virtual device is pointed at, much like the sensors in the real world "EyeCane" (Maidenbaum 2011)) and links it to a sound-file recorded from the "EyeCane"'s auditory output (the closer the object the higher the frequency of beeps). While in this case there is no difference to the user (who is either blind or blindfolded), the environments have a graphical output.

The environments are controlled using a standard keyboard and mouse. The software automatically tracks any activity within the virtual environments and stores it in a log file which includes information such as timing and the exact location of the device. The subject's answers were recorded by the experimenter.

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2.3 Experimental procedures and authorization

In all parts of the experiment subjects were seated comfortably in front of a computer and used a standard Mouse as the virtual cane. The virtual representation of the user was locked to place, and only the virtual cane could move in the XZ plane.

The experiment was approved by the Hebrew university ethics committee in accordance with the 1964 Helsinki Declaration, and all subjects signed informed consent forms.

2.4 Subjects

We tested 23 blindfolded sighted subjects (11 male, average age 25.1(22-32)) and 3 congenitally blind subjects (all female, average age 28(23-36), blindness due to peripheral injury). All subjects were healthy apart from their visual impairment.

3. RESULTS

3.1 Blindfolded sighted subjects

On all three tasks, subjects' performance (shown in fig 2) was significantly above chance (33% in tasks 1-2, 25% in task 3). In the 2D shape discrimination task the success rate was 61.1%±12.9%(SD) (p<5E-9, standard t-test). In the 3D orientation tasks subjects success level was 97.9%±5.7% (p<2E-27). In the final task of 3D shape recognition subjects success rate was 81.1%±17.8% (p<3E-13).

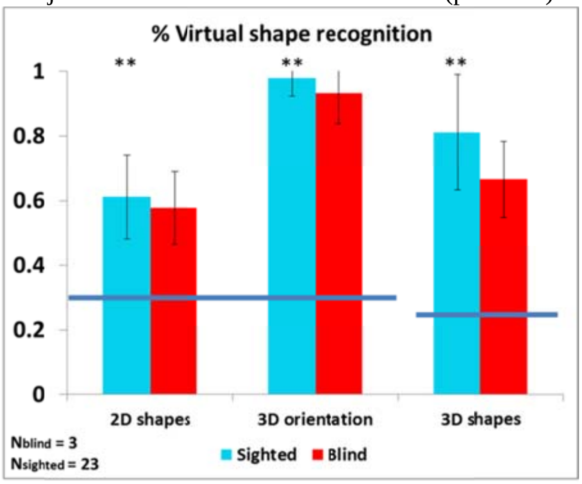

Figure 2. *% of correct answers in the 3 tasks for the blindfolded sighted (N=23) and for the blind subjects (N=3). error bars denote standard deviation. ** denote significance above chance level.*

3.2 In the blind

Initial results (shown in fig 2) from a small sample of 3 blind subjects, show that they were able to perform these tasks significantly above chance. In the 2D shape task they were able to discern the correct shape with a 57.7%±11.3%, which is significantly higher than the chance level of 33%. In the 3D orientation task subject correctly recognized the orientation with a 93.3%±9.4% success rate, with even higher significance above the chance level of 33%. In the 3D shape task their success rate of 66.7%±9.4% was still above the chance level of 25% but not as high as in the 3D orientation task.

The results of the blind subjects conform to those of the blindfolded in the first 2 tasks, but their performance is lower in the 3rd task.

4. DISCUSSION

Several studies have successfully shown that it is possible to recognize 2D virtual shapes using auditory information in various methods without vision (Amedi 2007, Chen 2011). Our work takes another step upon this path, and does so as part of a wider vision, of full interaction with virtual environments using the same concept - a virtual version of a virtual guide cane. Such interaction would help make virtual environments, whose importance is constantly increasing, more accessible to the blind and visually impaired population.

It should be noted that we are not the first to attempt to convey 3D virtual objects. Some previous attempts were made using tactile actuators to understand 3D virtual shapes. However, most such attempts required dedicated pre-processing, and unlike the widely accessible audio system used here, tactile actuators currently require a unique, and usually expensive, platform and are relatively low in resolution.

It is interesting to note that while the blind subjects described the tasks as very difficult, and described at first difficulty in conceptually understanding them, they too were able to successfully complete the 2D shape and 3D orientation tasks with a success level similar to that of the blindfolded sighted, and the 3D object task in a manner significantly above chance, even if less so than the blindfolded subjects. We anticipate that following brief training their performance will improve to levels comparable with the sighted here as well.

The extremely high success level in task 2, even with no training shows that this task is in fact far easier than expected, and that the basic ability to build a 3D mental image of a shape can be accomplished even in the absence of any vision, and even in the congenitally blind.

While further analysis is required to quantitatively assess this data, we observed that during the tasks several subjects developed scanning strategies, beyond simply semi-randomly scanning the virtual shape. One such strategy was to scan the whole virtual scene in a coherent manner (such as traveling back and forth along the whole scene in parallel lines) and another was to try to mentally envision the shapes and look for specific differences between them (such as looking for sharp corners using a 90°motion to differentiate the pyramid from the round shapes). Preliminary exploration of this data reveals that both strategies were more efficient than random scanning, while the second strategy was more efficient than the first

5. CONCLUSIONS

In conclusion, we have presented here a simple-to-implement system which the blind, visually impaired, and in some cases even the sighted, can use to understand 3D information by exploration. We have shown that this information alone is enough for the subject to recognize simple shapes and 3D orientations even without any training, indicating that this algorithm may serve as a useful tool for making virtual environments more accessible to the blind.

These results also lead us to view optimistically the potential use of the “EyeCane” in the real world for not only locating obstacles but also for a low-resolution understanding of main components of whole environments and their surrounding spatial layout.

Additionally, as these tasks and others using this technique can be performed safely while within an fMRI scanner we can utilize it to explore the creation of the novel sensory-motor loop in the groups of subjects to better understand the neural correlates of spatial representation and learning.

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Self-referencing virtual reality programs for neurorehabilitation

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ABSTRACT

Virtual Reality (VR) is a recent technology to assist in therapy and neurorehabilitation. In doing so, VR enables a realistic performance, with higher motivation and immersion in the problematic situation. VR increases ecological value and skills generalization; however this technology is still disorder-oriented. Patient's response to treatment differs from patient to patient. So it is relevant to take into consideration a multitude of aspects, self-referencing VR Programs for Neurorehabilitation. We argue the need to create a variety of scenarios that better adapt to psychological, developmental and ecological characteristics of each patient.

1. INTRODUCTION

Technology-assisted therapeutic approach is an important tool in therapy and neurorehabilitation, with benefits such as increasing access to services for rural individuals, portability, improved self-monitoring, improving efficacy of treatment (Newman, Szkodny, Llera, & Przeworski, 2011).

Virtual Reality (VR) is a recent technology, used in technology-assisted intervention that enables patient's increased sense of presence and immersion within a computer-generated simulated environment (Bioulac et al., 2012; Parsons, 2004; Tyndiuk et al., 2007; Wuang, Chiang, Su, & Wang, 2011). Besides increasing patient's motivation towards therapeutic intervention (neuropsychological or psychological), VR enables a more realistic task performance, meaning better ecological value and better skills generalization to other life contexts (Bioulac, et al., 2012).

However, even if VR improves rehabilitation outcomes in different pathologies (e.g., anxiety, ADHD, depression, stroke, traumatic brain injury, dementia), this approach is still disorder-oriented and we are just starting to understand the relevance of factors as the patient's characteristics and limitations (Tyndiuk, et al., 2007). A more personalized intervention is the next step in the relatively new application of technology to neurorehabilitation.

2. PERSONALIZED VIRTUAL REALITY

In Medicine, general therapeutics are being replaced by a personalized medicine approach. In fact, since the human genome sequencing, in 2003, and the advances in proteomics, pharmacological treatment is heading towards a tailored intervention, attending individual characteristics, thus increasing outcome (Meyer & Ginsburg, 2002).

Disease course and patient's responses to treatments varies from patient to patient and should be taken into consideration while designing neurorehabilitation programs and materials. But even more important than the patients' disorders and its general or individual history, are patients' characteristics in a multitude of aspects may be critical for the outcomes of the intervention. For example, by patients' characteristics we don't just mean the previous task experience, or VR experience, or any other isolated feature, such as cognitive capacity (Tyndiuk, et al., 2007). We also mean the patient as a whole person, with interests, values, expectations, fears, personality, a particular family and social environment, etc. In fact, we argue that these

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later factors and the way they interact are even more relevant for the success of VR Neurorehabilitation Programs.

While a neuropsychological evaluation is crucial for the outcome prediction of Neurorehabilitation VR Programs, as they determine baseline and prognosis, individual characteristics are of the upmost importance for patient's motivation towards the intervention and for maximizing outcome (Santos, 2005; Wilson, Gracey, Evans, & Bateman, 2009). Therefore we argue that we manage to develop more personalized VR Programs, creating different scenarios for the same task, and allowing each patient to extract a self-referenced meaning from these scenarios, we will raise the odds of success. We do not argue about a different scenario available for each patient, as it wouldn't be financially possible, but a different scenario tailored for a group of patients with similar individual characteristics, including life experiences. We argue about the need for user-profile typologies as the psychological, developmental and systemic profile of each patient and the acknowledgment of their individual references.

In fact, an accurate neuropsychological and psychological evaluation will enable the professionals to determine the individual characteristics, and then patient's insertion in smaller groups, more homogeneous in their user-styles and needs. For instance, if the patient is a boy, he might like football but also he could prefer martial arts or an action figure's animation series. Simulating tasks in such environments, according to each child's interests, would increase outcome and improve generalization, as the situation is much more self-referenced and meaningful. However, if the patient is a sexagenarian woman, she could respond better towards playing with children, shopping for groceries or even a walk in the park, depending on her individual characteristics.

Next step in Neurorehabilitation VR Programs should be having different scenarios available, in order to better adjust to patient's real needs and expectation, thus increasing patient's motivation, participation, generalization and overall outcome maximization.

3. DEVELOPMENTAL APPROACH

As important as the ecological approach (simulation of daily life situations), patient's developmental stage should be determined as people of the same age often have different life experiences and different perceptions of the world.

Determining patient's perception enables the professionals to better understand how to reach to each patient. Without forgetting the work of Freud, Piaget, Erikson, and many others, it seems also relevant to integrate the notion from Robert Kegan's developmental theory of the *evolving self*. According to this author (Kegan, 1982) the human self oscillates from psychologies favouring inclusion and psychologies favouring independence along lifespan (Figure 1).

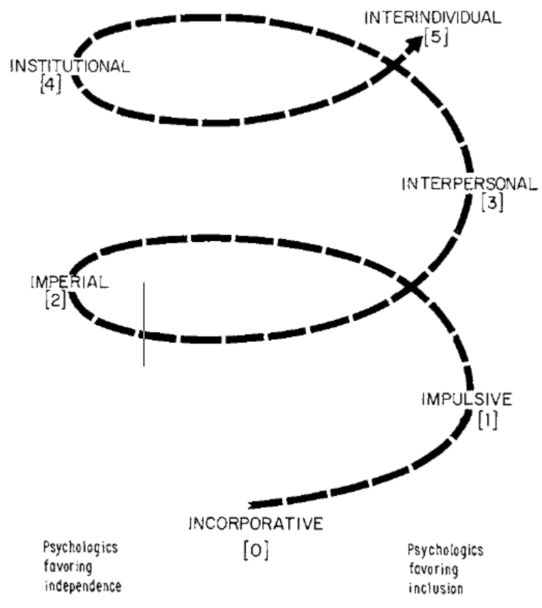

Figure 1. *Kegan's helix model of the evolving self.*

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Knowing in which developmental stage the patient is will allow the rehab professionals to motivate and promote generalization to other life contexts, as the simulation and the story behind the simulation becomes more significant for that patient. This would presumably enable the patients to upgrade their inner speech and perceive themselves as capable of performing the rehabilitation tasks not only in a VR environment, but also in real life situations.

4. HOLISTIC MODEL OF INTERVENTION

Along with *user-styles and needs* as the individual's psychological, developmental and systemic profile, a comprehensive model of neurorehabilitation is also needed. Health professionals, families and patients should meet and agree on appropriate neurorehabilitation goals (Wilson, et al., 2009) and involve family as much as possible in VR Neurorehabilitation Programs as their understanding of it is crucial for patient's generalization.

The Holistic Approach first appeared in the 1970's (Santos, 2005). This approach offers integrated multimodal treatment attempting patients acceptance of altered life status and self-awareness of impairment, by teaching compensatory strategies for coping with residual deficits (Diller & Ben-Yishay, 2003). VR Neurorehabilitation Programs can be far more comprehensive than other computer-based tasks for cognitive training, or even other computer-generated simulation programs. Nevertheless, it is necessary to combine technology with a multidisciplinary team of professionals pairing with the patients' physical and psychological needs, their families, significant others, etc. Thus, such holistic Neurorehabilitation VR Program comprehends three major modalities of treatment: therapeutic milieu, cognitive remediation (VR sessions included) and psychotherapy (Diller & Ben-Yishay, 2003). Always adapted to each patient's individual characteristics, development stage, personal history, life experiences, and social context. Always considering user's styles and needs.

5. CONCLUSIONS

Each patient lives in a different context, in a different cultural environment, conducting to even more different personalities and individual aspects. Each disorder has different stages and could affect patients in different developmental stages.

Health professionals must be aware of this and respect patient's individuality. A self-referencing approach to VR programs will increase patient's motivation and skills generalization, better aiding psychotherapy and neurorehabilitation. Therefore, while programming, professionals should create a group of possible scenarios and the possibility of creating a new one, based in patient's preferences. In doing so, patient's outcome should be even better than in normal VR neurorehabilitation programs, as it better suits each patient's needs. A change of paradigm is in order with further research necessary.

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Configuring a mobile platform for daily-life management following brain injury: a case study in ubiquity, agility and ethics

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ABSTRACT

This paper offers a case study of a participant experiencing neurological impairments after brain injury who uses his mobile platform to author the management of his daily life. The study draws on the participant's own descriptions to propose delineations of the tropes 'ubiquity' and 'agility' with reference to technology participation in daily life. The study attends to an ethical research matter of privacy in the study of daily-life management, not least where the participant has recorded others' personal details. In conclusion, ethical parameters are established for a closer study of technology ubiquity and agility in daily life after brain injury.

1. BACKGROUND

1.1 Introduction

Steven (pseudonym) is in his mid-forties and suffered his brain injury 12 years previously as a result of a motorcycle crash. He continues to experience severe impairments to his short-term memory, and is now an active volunteer at the Headway East London day centre. Headway provides practical support to people experiencing impairments and other difficulties following brain injury. Prior to his injury Steven was a senior professional and continues to maintain professional links with his employer. Steven used mobile phones routinely before his injury and now exploits a range of smart phone apps to support various aspects of the management of his daily life. The platform is the widely adopted technology array, iPhone,. which comprises telephony, photography and imaging, data management, networking capability and a hand-held, touch-sensitive interface. Specifically, iPhone 4 16Gb, Steven uses iCalendar, iNotes and iSpreadsheet for his daily-life management, which, he reports, are sufficient for his requirements.

Steven's profile, level of disability and use of the iPhone platform are not representative of the Headway membership as a whole; yet his agile manipulation of the technology array provides a valuable case study in the investigation and development of mobile technologies at the intersections of psychological, social-spatial and technological domains. For the purposes of the study, 'technology' refers to the mechanically supported organisation of experience. This follows Heidegger's classic account of technology as providing a 'framework' for experience and as readying the availability of resources. A full discussion is beyond the scope of the present study, (cf. M Heidegger, 1954/1993; a further, related discussion of technology in practice is offered by Ingold, 2000:296-299)

The present study was associated with a longer-term map-making project, led by the present investigator in collaboration with Headway staff and members (O'Brien, 2012). Some of the maps were produced with the aid of an iPhone, which revealed to the investigator an exploitation of that platform with a greater range of modalities than had been anticipated prior to the study.

1.2 Objectives

The study had a three-fold objective: (i) to produce a case study of iPhone configuration as an assistive technology to daily life following brain injury, (ii) to delineate the tropes 'ubiquity' and 'agility' in terms of present study, and (iii) to help design ethical parameters for a closer study (at a later date) of these tropes among both brain-injury and general populations. The rationale is that Steven's multi-modal, multi-domain application of iPhone functionality to his everyday life provided a particularly well focused and stabilised examination of these themes.

Ubiquity does not appear to be well defined in the field of technology studies, and does not appear to have been delineated with reference to daily life after brain injury (searches undertaken using Google Scholar, Web of Knowledge and institutional library databases). The popular reception of the term *ubiquitous computing* may perhaps be parenthesised as 'the global network of devices and instrumented objects' (cf. Castells, 2010:51-53). The design framework *agility* is already well established in software engineering (Cf. *Manifesto for Agile Software Development*, 2001, however the present study considers this trope in terms of person-specific authorship. Hence, Steven's use of his iPhone offered a unique opportunity to delineate what we mean by 'ubiquity' and 'agility' with reference to technology configuration in daily life following brain injury. The investigator proposes that these delineations may also apply to daily life technologies among the general population.

Headway's psychologist raised the critical ethical issues of participant task-loading and/or privacy. For those experiencing difficulties in daily life, participation in research may increase cognitive loading; while impairments to judgement, working memory, and so on, may compromise the right to privacy. The investigator acknowledged these ethical constraints, also considering their imperatives among a general population.

1.3 Methods

Steven became involved in the project via an earlier map-making study involving day-centre participants. Steven had helped another Headway member make a photographic 'map' of a regular route using his iPhone. The investigator only became aware of Steven's intensive use of the iPhone platform during a videoed debriefing session. Steven volunteered the information about his prior iPhone usage and invited the investigator to film a demonstration of his routine iPhone activities. During the video session, the investigator led further discussion about Steven's activities.

The investigator surmised that typical difficulties following brain injury may be regarded as intensified versions of experiences that are common to most people (including forgetfulness, disorientation, fatigue, matters of self-esteem, and so on). Hence, the methods and constraints of this study would apply to a similar but diversified study among both brain-injury and general populations.

More formally, the methods comprised an overt, ethnographic laboratory-based observation, analysed via a loose *grounded theory* framework, after Glaser and Strauss (1999), salient quotes are provided below. The observation was of an authored configuration of a mobile technology array at the intersections of person-specific, multi-modal domains. The follow-up study pertaining to ethical considerations was undertaken through a semi-structured interview.

2. A MOBILE PLATFORM FOR DAILY-LIFE MANAGEMENT

Steven described how, in the period immediately following his brain injury 10-12 years previously, he kept a notebook to help overcome his short-term memory impairments. However, his iPhone (which is "more than a phone") came to afford the advantage of routine back-up of his notes on a personal computer. Steven also creates classifications for notes based, for example, on a person's name or a type of task to be undertaken. Other notes are photographic, including items for his regular shopping list. This means he is better able to keep track of events and experiences that have occurred the previous months and years.

Steven maintains that the iPhone does not replace his short-term memory but serves to "commentate" items and events. He reflects that, as his memory is impaired, a platform with limitless capacity affords greater personal security. Hence, he is better able to keep a record of items over several years as, "You don't know what you're going to need to recall, so you have to make notes. That's the uncertainty. I delete things very rarely".

Steven showed the investigator some notes taken recently: the location of his car, a problem with his gas supply and plumbing, the reason for a meeting being cancelled, an important web link, what he has recently eaten, copies of important email correspondence, cash loans, orders he has placed including expected delivery dates, items he has lost including the date when the item was last seen.

Steven describes that being able to remember what he did during the previous few days, including what he ate, is important to him. This is because he likes to tell others what he has been doing when he is not able to readily recall these activities. In addition, he maintains a record of his meals from the previous 12 months, from which is able to compile a current shopping list: "By copy and pasting I always get the right one."

Reflecting further on his post-injury adoption of the iPhone, Steven reports: "My life is a big mirage of systems or strategies; strategies of how to cope. It's also about insight, about knowing I can't recall it and

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referring to something I can rely on. I never had an iPhone, or an organiser, before my injury – because I [now] need to... to recall the information I need to recall."

Figure 1. *Steven demonstrating his note-taking of daily activities.*

3. UBIQUITOUS AND AGILE CONFIGURATION

The present case study considers Steven's iPhone configuration at the intersection of his psychological, social-spatial and technological domains. The investigator noted how Steven's participation in the iPhone platform enacts the functions of this multi-faceted practice space: capturing, classifying, organising, scheduling and transferring information. Hence, Steven's iPhone is not a merely device-tool for instrumenting his daily life, but an inscriptional platform by which he authors the salient features of his person-specific functional domain (ie so as "to recall what I need to recall").

Steven volunteered some rapid demonstrations of how he uses his iPhone. The investigator was impressed by the agility of his platform configuration, both in terms of practical interaction (using thumb and index finger as is common, see *Figure 1*) and in functional organisation. Steven's itemising and classifying of groceries, meals, transport and social activities is attended to as a near-continuous and concurrent task of modification. For example, whereas Steven used to place an empty milk bottle by his front door as a reminder to buy fresh milk, he now uses his iPhone to rapidly encode the task schedule. Hence, he takes a photograph of the item, allocates it to a groceries inventory and applies to the item a due date for purchase.

To generalise, we may argue that, in the present context, it is the capacity for continuous, concurrent authorship that defines a 'ubiquitous' platform. Hence, ubiquity is not so much 'technology everywhere' (instrumented) but is the 'organisation of everything' (authored). Observing Steven's practice, we may define agility in the present context as a capacity for the rapid and iterative formulating of salient features in the environment (supported by a highly intuitive interface). By extension, we might argue that 'agility' is the practice-orientated counterpart to the spatial paradigm of 'ubiquity'.

4. UBIQUITY AND ETHICAL CONSTRAINTS

The investigator arranged a follow-up interview with Steven 11 months after the initial video session. By recapping some of the initial enquiries (pertaining to technology participation in everyday life), it became clear that Steven had maintained a stable and consistent lifestyle in which his iPhone remains an important technology array for everyday management. The investigator outlined to Steven what we mean by 'ubiquity' (as defined above) and whether he recognised this trope with reference to his own practices. The investigator also outlined to Steven the possible ethical barrier of privacy to closer qualitative research.

Steven grasped the notion of 'ubiquity' as a matter of authorship and 'agility' as that of continuous, concurrent modification. In response, he reiterated some of the everyday management examples he gave in the earlier session as well as his daily routine of backing up the day's notes. The investigator proposed that examining the content of his notes could comprise a further study, but that this would demand ethical constraints for privacy. Steven remarked that he would be happy for the full content of his iPhone notes to be made available for research, but did not appear to grasp its wider ethical implications. An outstanding matter is that Steven records activities of his friends and family members, which include inferences of their personal relationships. Steven's ability to judge the complex matter of others' privacy remains unknown and, as this does not affect his everyday life, it is not reasonable to request a formal assessment. Steven's capacity in this regard is ethically unknowable within the scope of the research project, a condition that might apply to any participant in a study of this kind.

5. RESULTS

The investigator's aim was to produce a case study of iPhone configuration as an assistive technology to daily life following brain injury, and to help determine ethical parameters for a closer study of ubiquity and agility among both brain-injury and general populations. While the study successfully tested the notion of ubiquity as defining a style of person-specific, multi-domain authorship (as distinct to universal instrumentation), the investigator found an ethical constraint for closer qualitative analysis in that Steven made notes of others' activities. Moreover, it is not reasonable to request that Steven undergo a formal assessment of his ability to judge ethical issues when this has not been raised as a matter of concern in his everyday life.

Steven has provided a key metaphor for further study in his "mirage of systems and strategies". In this regard, he outlined how he "commentates" his items, events and experiences, which suggests to the investigator a level of concurrence or synchronicity beyond what we normally refer to as annotation. Steven's commentated notes take many forms; those outlined here include locations and schedules, problems and rationales, informational details, financial matters and purchases, meals and groceries, encounters and communications. Hence, an ethically constrained study may examine the practice routines by which person-specific knowledge is strategised (e.g. captured, taxonomised, scheduled, recalled) and transferred into situated actions (cf. Suchman, 2007:69-84).

In conclusion, participation in mobile platform arrays for everyday management appears to warrant further study among diverse populations (including those who experience neurological impairments and those who do not). The definition of ubiquity as a matter of authorship would also benefit from diversified examination in this regard, while agility in platform configuration would provide a related focus of further enquiry. The present study revealed that qualitative study must be ethically constrained to anonymised interviews and controlled observations; that it is not reasonable to *formally* assess a participant's abilities (e.g. to judge complex ethical matters) that do not otherwise affect daily life. Finally, as a general matter, an ethical constraint applies to the access of the contents of personal notes.

Acknowledgements: I would like to thank the staff members and volunteers at Headway East London who have supported and contributed to the broader study of experience, representation and technology after brain injury. In particular, I am very grateful to the participant who made the present study possible.

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Development of a system for the assessment of a dual-task performance based on a motion-capture device

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ABSTRACT

The authors produced a dual-task (DT) which provides a dynamic balance task and a cognitive task in a game system using motion sensors and virtual images. There had been no DT where a cognitive task needs a dynamic balance task which requires full body motions. We developed and evaluated a game system to assess the performance of the DT. The DT is to solve Sudoku using full body motions like Tái Chi. An ability to perform a DT is intimately related to risk of falls. To evaluate the developed system, we compared the performance of elderly people and young people. Generally, elderly people are at a higher risk of falls. 20 elderly community-dwelling adults (mean age, 73.0 ± 6.2 yrs.) and 16 young adults (mean age, 21.8 ± 1.0 yrs.) participated in this study. To compare the two groups, we applied an independent-samples *t*-test. The time taken for the elderly people was 60.6 ± 43.2 seconds while the time taken for the young people was 16.0 ± 4.8 seconds. The difference is statistically significant ($p < 0.05$). This result suggests that the developed game system is useful for the evaluation of the DT performance.

1. INTRODUCTION

Falls are fairly common among elderly people. Blake et al. (1988) showed that 35 % of elderly people aged 65 years and over reported one or more falls in a year. Load and Ward (1994) pointed out that people beyond age 65 increase sway areas because their reduced vision is less able to supplement peripheral input than younger people. Since falls of elderly people often result in fractures, it is important to predict these falls and prevent them.

It is widely recognized that balance disorders of elderly people are related to multiple impairments, such as weakness and cognitive impairments (Tinetti et al, 1995). Lundin-Olsson, Nyberg and Gustafson (1998) reported a novel method for risk analysis of falls based on dual-task (DT) performance. A DT can be consisted of a combination of a dynamic balance task and a cognitive task. An example of an effective dynamic balance task is Tái Chi, which is based on full body motions. Leung et al. (2011) demonstrated that Tái Chi reduces falls in the non-frail elderly. Also, an example of an effective cognitive task is Sudoku. Sudoku is a logic-based puzzle known familiarly in the world. Nombela et al. (2011) showed that cognitive training based on Sudoku exercises improves the cognitive performance of Parkinson's patients in the Stroop test. Though each performance of a dynamic balance task or cognitive task can be assessed easily, it is more difficult to assess DT performance involving two tasks. Yamada et al. (2011) considered that the evaluation of the performance of the secondary task is insufficient in the previous research using DT protocols. For assessing DT ability, they developed a smartphone-based application where a player is required concurrently to walk and to roll a virtual ball on a smartphone using his or her wrist. However, there has been no DT where a cognitive task needs a dynamic balance task which requires full body motions. In this study, the authors develop a DT where a cognitive task needs a dynamic balance task which requires full body motions. We use Sudoku and Tái Chi as a cognitive task and a dynamic balance task, respectively. Moreover, we realize to assess DT performance involving two tasks.

2. OBJECTIVES

Suppose that the authors made large Sudoku instances using physically large grid and blocks to require full body motions. A player solving the Sudoku instances would be difficult to recognize the large instance because they must be near the instance to solve it. Hence, we project a player to a figure on a screen and

superimpose an instance of Sudoku on the same screen. When the instance is large compared to the figure on the screen, a player is required to use full body motions. Also, since there is an appropriate distance between the player and the screen, he can recognize the instance.

We produce a DT which provides a dynamic balance task and a cognitive task at the same time in a game system using motion sensors and virtual images. The DT is to solve Sudoku using full body motions like Tái Chi. We also develop a system to assess the performance of the DT and evaluate the proposed system.

3. METHODS

Characteristic full body motions of Tái Chi include spreading the hands wide, bringing them close, spreading the legs wide, bringing them close, or combinations of these. A subject is asked to do these characteristic full body motions, which are then navigated to solve Sudoku – in other words, the subject is given an instance of Sudoku and asked to put digits into the vacant boxes provided using the full body actions. The authors produce a DT which provides a dynamic balance task and a cognitive task at the same time in a game system using motion sensors and virtual images. The DT is to solve Sudoku using full body motions like Tái Chi. We also develop a system to assess the performance of the DT and evaluate the proposed system. (Figure 1 depicts the diagram of the DT and the system we develop.)

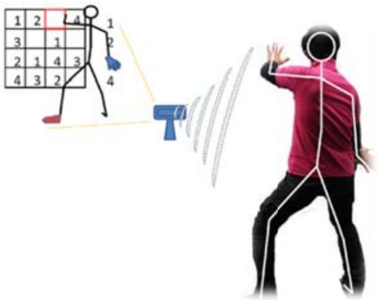


Figure 1. *A conceptual diagram of the DT and the developed system.*

3.1 System configuration and system operation

The game system to provide the DT with the assessment of the DT performance consists of a motion-capture device, a computer, a screen and a projector. Kinect (Microsoft Co.) is used as the motion-capture device. Figure 2 depicts the configuration of the game system. We describe the system operation according to figure 3, which depicts the flow chart of the game system.

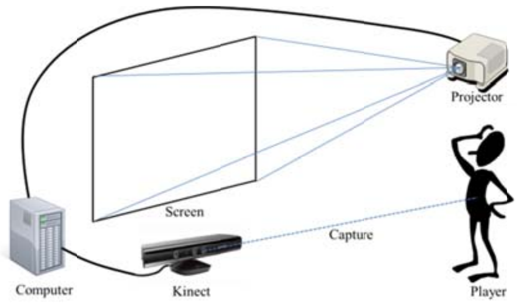


Figure 2. *A configuration of the game system.*

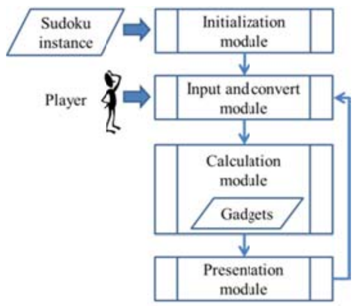


Figure 3. *A flow chart of the game system*

3.1.1 Initialization module. First, the initialization module prepares a rectangular workspace in the computer's memory. The initialization module loads a Sudoku instance and lays out the instance on the workspace. The Sudoku instance consists of a 4×4 grid (16 boxes). 13 boxes are initially filled with digits from one to four. Many Sudoku instances are prepared in advance. The initialization module chooses one of them at random.

3.1.2 Input module and convert module. The game system uses Kinect for XBOX 360 as a motion-capture device. The equipment has an infrared projector and an infrared camera. The resolution of the infrared camera is QVGA (320×240) and the horizontal and vertical fields of view are 57 degrees and 43 degrees, respectively. The camera can detect physical objects in the distance between 1.2m–3.5m and it expresses the depth per each pixel using 16-bit mono. The frame rate of the camera is 30 frames per second. An input

module receives the physical object data by utilizing Kinect and Kinect for Windows SDK Beta 1. The information includes the position and the shape of a player. A convert module extracts the physical object data related to the player, converts the data to skeleton information including positional information of joints, and lays out the skeleton information on the workspace in the computer's memory. The convert module also exploits Kinect for Windows SDK Beta 1.

3.1.3 Calculation module. A calculation module lays out gadgets which are digits from one to four and a circle. The digits from one to four and the circle are laid out as far as the right hand joint and the left foot joint of the skeleton can reach, respectively. (Note that the game system supposes that the player stands right in front of Kinect.) The calculation module determines if the following conditions are satisfied. (i) The right hand joint overlaps one of the digit gadgets. (ii) The left foot joint overlaps the circle gadget. (iii) Both the right hand joint and the left hand joint overlap one of the vacant boxes in the grid of the Sudoku instance. (As a reference, see figure 4 in advance.) When both (i) and (ii) are satisfied, the player grabs a corresponding digit. When the player has a digit and both (ii) and (iii) are satisfied, he or she can try to fill the vacant box using the digits. When the digit is correct depending on the rule of Sudoku, the vacant box becomes filled.

3.1.4 Presentation module. A presentation module presents the Sudoku instance, the skeleton information, and the gadgets on a screen. The skeleton information is shown as a stick figure. The images of a glove and a shoe are superimposed on the right hand joint and the left foot joint so that the player recognized them easily. In addition, when all the vacant boxes become filled, the time taken to fill them is measured and displayed. The display size can be changed freely. Figure 4 depicts the display of the game system.

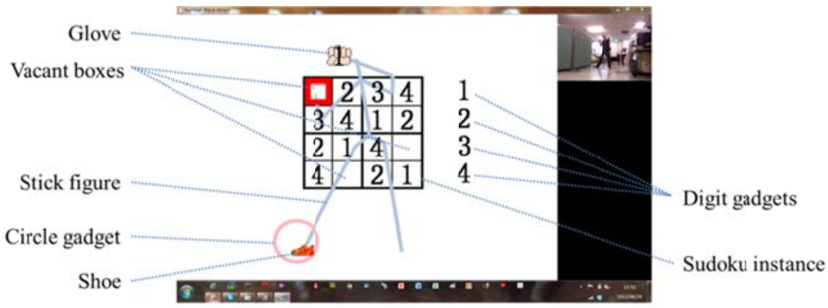


Figure 4. *A display of the game system on a screen.*

3.2 Game scenario

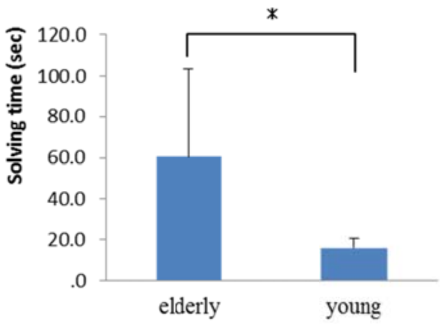
The player is asked to put digits into the remaining three vacant boxes. First, the player is requested to select a digit using gadgets to fill vacant boxes. Digit selecting makes the player spread his or her hands and legs. Next, to put the selected digit into a vacant box, the player is requested to select the vacant box. The player must get the right hand close to the left hand. Concurrently, since the player must follow the rule of Sudoku, the game requires cognitive skill. The player finishes the DT game when he or she fills all the three vacant boxes. The system measures the time taken to solve the DT.

3.3 Evaluation

To evaluate the developed system, the authors compared the performance of elderly people and young people. Generally, elderly people are at a higher risk of falls. 20 elderly community-dwelling adults (mean age, 73.0 ± 6.2 yrs.) and 16 young adults (mean age, 21.8 ± 1.0 yrs.) participated in this study. To compare the two groups, we applied an independent-samples *t*-test, where a *p* value of <0.05 was considered statistically significant.

4. RESULTS

Fig 5 depicts the result of the evaluation. The time taken for the elderly people was 60.6 ± 43.2 seconds while the time taken for the young people was 16.0 ± 4.8 seconds. The difference is statistically significant ($p < 0.05$) though the variability reported for elderly group was large. This result suggests that the developed game system is useful for the evaluation of the dual-task performance.



Statistical significance (*: $p < 0.05$)

Figure 5. *A comparison between elderly and young people of the time taken to solve the DT.*

5. DISCUSSIONS

Since the difference of the time taken to solve the DT for elderly people and young people, the game system may be able to assess risk of falls. The authors will continue to evaluate the system by comparing with single tasks of the DT and other physical performance tests that are widely used to identify high-risk elderly adults.

In the experiments, almost all the subjects said that they wanted to try the game system again. That is, they seemed to feel the DT interesting. If the game system is enough interesting for players to continue playing the game, we can evaluate whether the game system is used as a training device.

Negative feedback of the subjects was not given in the experiments. It may mean that the subjects were performing the movements as expected and that the system could obtain skeleton information including positional information of joints to succeed at the DT game.

6. CONCLUSIONS

The authors developed and evaluated the game system based on a DT which provides a dynamic balance task and a cognitive task. In the game system, a Sudoku instance is given to a player. The player is required to solve the instance using full body motions like Tái Chi. The result of the experiment suggested that the developed game system is useful for the evaluation of the dual-task performance.

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Counting repetitions of upper extremity movements while playing video games compared to traditional therapy: implications for stroke rehabilitation

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ABSTRACT

Clinicians are seeking novel methods to increase the number of repetitions of purposeful movements during and following stroke rehabilitation. Video-game consoles encourage active purposeful movement, however, the number of repetitions while playing video games is unknown. We aimed to compare the number of repetitions and accelerometers activity counts of movements of the weak upper extremity of individuals with chronic stroke while playing video games to participants in traditional therapy. Eight participants were included. Differences between groups in the type and number of repetitions and accelerometers activity counts were found. These preliminary findings indicate that video-games facilitate multiple repetitions of fast purposeful movements.

1. INTRODUCTION

Stroke rehabilitation is considered a re-learning process in which motor learning mechanisms are operative and interact with spontaneous recovery (Krakauer, 2006). Full functional use of their weaker upper extremity occurs only in 10-20% of the individuals poststroke (Broeks et al., 1999). Despite the fact that it is recommended that these individuals move and use their weak upper extremity in order to facilitate its recovery and brain plasticity (Nudo, 2007), many individuals do not use their weaker arm enough and limited repetitions of movements have been recognized. For example, Lang et al. (2009) observed in-patients in stroke rehabilitation to perform only 39 repetitions of active movement, 34 repetitions of passive movement, and 12 repetitions of purposeful movements during a single session of occupational or physical therapy. In a recent study, using accelerometers during in-patient stroke rehabilitation, the amount of activity counts did not increase significantly from admission to discharge, despite the fact that all of the clinical measures improved significantly (Rand and Eng, 2012). This is known as the “Learned non use” phenomenon (Taub, 1980). Since the disuse of the weak upper extremity can lead to serious complications such as muscle atrophy, contractures, pain and bone loss (Pang et al., 2007), clinicians are seeking novel methods to increase the number of repetitions of purposeful movements during and following rehabilitation.

Virtual Reality (VR) enables the interaction with virtual objects in virtual environments which encourages movement and motivates the user (Weiss et al., 2009). Costly VR systems in addition to off-the-shelf video game consoles (e.g. Sony PlayStation EyeToy, Nintendo Wii) have been found to have great potential to encourage active purposeful movement (e.g. Mouawad et al., 2011), however, the number of repetitions of upper extremity movement while playing video games as opposed to traditional therapy is unknown.

Our study objectives were: 1) to compare the number of repetitions of movement of the weak upper extremity of individuals with chronic stroke who were observed while participating in a group playing video games or in a group receiving traditional therapy, 2) to compare the number of accelerometer activity counts and movement intensity of the weak upper extremity of individuals with chronic stroke while participating in a group playing video games or in a group receiving traditional therapy.

2. METHODS

2.1 Procedure

Participants wearing two wrist accelerometers were video-taped while participating in two therapeutic group sessions and the number of repetitions of their weak upper extremity were counted. These individuals were part of a randomized controlled trial (RCT) receiving motor intervention via playing video games (VR group) or via traditional exercises (traditional group). Individuals in the RCT who provided written informed consent, were randomly allocated to one of the two groups and received group therapeutic sessions for three months (1-h-sessions, 2 sessions/week). Individuals in the VR group played video games (such as the XBOX Kinect, Sony PlayStation Eyetoy and MOVE) which encourage active movement especially of the upper extremities and trunk. Individuals in the traditional group were also encouraged to perform active movements by performing exercises using instructions, functional tasks and therapeutic aids such as balls, blocks and cones. Participants in both groups were encouraged to use their weaker upper extremity, and if not possible, they were instructed to move their weaker hand with the stronger hand.

2.2 Counting Repetitions

Participants were video-filmed throughout two full sessions during the third month of this 3-month intervention program. Trained assessors (occupational therapists) watched the video films and observed each participant during each session and counted the upper extremity movements according to the observation guide by Lang et al. (2009). Upper extremity movements were classified as active or passive exercises or purposeful movements. **Active exercises** were defined as "any movement where the patient was instructed to move the limb from an initial resting position through a specific motion and return it to the resting position" (pp. 4) such as shoulder abduction or elbow flexion**. Passive exercise**s were defined as "any movement at the patient's joint(s) made by the therapist or another outside source" (pp. 5). If the participant used their stronger upper extremity to move their weaker upper extremity, it was considered passive as well. Passive exercises included for example shoulder abduction/adduction or elbow flexion/extension. **Purposeful movements** were defined as "as any movement that accomplishes or attempts to accomplish a specific and usually functional goal or any movement that simulates a specific functional task" (pp. 5), such as reaching for a real/virtual object, rolling or throwing a (virtual) ball, touching or grasping a real/virtual object. The mean number of movements was calculated from observed movements in both sessions/2.

Prior to the observation, four assessors were trained how to count the different types of movements. Following the training, the reliability between the four assessors was tested by having them simultaneously observe four different participants for 5 minutes each. Interrater reliability ($ICC_{3,1}$) between the four raters was 0.98 (p<.001).

2.3 Quantifying Upper extremity Movement

During these two sessions participants also wore two small Actical (ActicalTM , MM; Mini-Mitter Co.) accelerometers on their wrists. The reliability and validity of these accelerometers for the upper extremity of individuals with stroke have been established (Rand and Eng, 2012). The accelerometers provided the number of activity counts and intensity of movement (0=sedentary to 3=vigorous) for each hand. The mean number of activity counts and intensity was calculated as a mean of the two sessions.

2.4 Characterizing the Study Population

Community-dwelling individuals with chronic stroke who were cognitively intact and able to walk participated in this study. Four participants from each group have been video-taped so far. The participants observed from each group were matched according to their upper extremity motor impairment, as assessed by the Fugl-Meyer Motor Assessment (FMA) (UE subtest) (Fugl-Meyer et al., 1975), a validated and reliable assessment. Scores range from 0 points (no active movement) to 60 points (full active movement). Due to the small sample, descriptive statistics and frequencies were utilized. The number of repetitions, accelerometers activity counts and intensity are presented as the median [Inter quartile range (IQR)].

2.5 Data Analysis

Due to the small sample, descriptive statistics and frequencies were utilized. The number of repetitions, accelerometers activity counts and intensity are presented as the median [Inter quartile range (IQR)].

3. RESULTS

3.1 Participants

To date, we have counted and analyzed the number of repetitions of eight of the participants [mean age (SD) 55 (10)], an additional 10 participants will be added. The groups were similar in terms of upper extremity motor impairment; in each group, two participants had limited upper extremity movement (5-20/60 points on the FMA) and two had nearly full upper extremity movement (46-59/60 points on the FMA).

3.2 Upper extremity repetitions

In the VR group, participants were observed to do 0 upper extremity active or passive exercise movements as opposed to a median (IQR) of 63.5 (9-117) upper extremity active and 11.7 (0-55) passive exercise movements in the traditional group. However, participants in the VR group were observed to perform a median (IQR) of 255 (0.7-581) purposeful upper extremity movements compared to 46 (10-62) purposeful movements in the traditional group.

3.3 Accelerometer data

The median (IQR) accelerometer activity counts of the weaker and stronger upper extremities of the participants from both groups for one-hour therapeutic session are presented in Figure 1. As can be seen, higher accelerometers activity counts were registered for both hands of the participants in the VR group compared to the participants in the traditional group. The median (IQR) intensity of the weak upper extremity in the VR group was 2.2 (1.8-2.6) and 1.9 (1.7-2.0) in the traditional group.

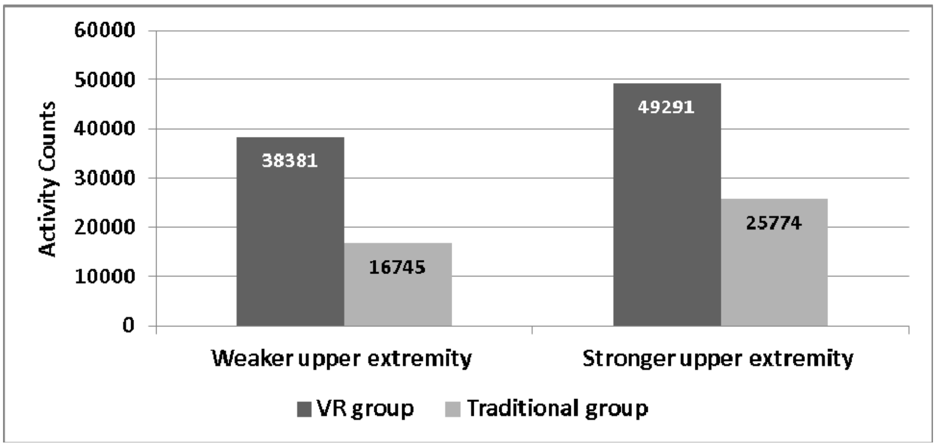

Figure 1. *Median accelerometer activity counts from both hands (weaker and stronger) of participants from the VR group (N=4) and the traditional group (N=4) while participating in a therapeutic session.*

4. DISCUSSION

Counting the number of upper extremity repetitions highlighted the differences between the motor interventions provided to the two groups. Whereas the participants in the traditional group performed active and passive exercises, those in the VR group did not perform exercises at all; their upper extremity repetitions were all purposeful movements aimed at touching virtual balloons, throwing or bouncing balls, fighting warriors, blocking leaks, cutting cucumbers, etc. These repetitions translated into a median of 38,381 activity counts, which is more than double the activity counts monitored for the participants in the traditional group (16,745).

Eliciting repetitions of upper extremity movements is important poststroke since it may facilitate the recovery of the upper extremity. More so, the higher levels of accelerometer activity counts reflects not only more repetitions of movements but also higher intensity of movements. Playing video games seems to facilitate individuals to move faster, which may be an effective way of increasing rehabilitation intensity after stroke (DeJong et al., 2012).

5. CONCLUSIONS

Differences between groups in the type and number of repetitions and accelerometers activity counts were found. The use of commercial video games encourages multiple repetitions of faster movements in a fun,

motivating and inexpensive manner. Further studies are required to assess the effectiveness of this type of intervention for individuals post stroke.

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Promoting ability with interactive artistic environments

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ABSTRACT

The intention of this project derives from the beauty of the field of arts and from interaction and immersion paradigms, which are today potentiated by multisensory and multimodal feedback in technological environments. We wanted to see the impact of interactive artistic environments on students with special needs, as a form of self-expression and inclusion, in a real school context. Emphasizing the actual Portuguese inclusive school framework, this study was carried out in a public education establishment, with twelve students from individualized special curricula. *Special INPUT* was the concept of different types of environments and interaction approaches were implemented in individual sessions with the participants, which allowed to promote and observe their intellectual, emotional, personal, interpersonal, intrapersonal, psychomotor and artistic skills. At the moment, we have not yet closed the study, so our presentation focuses on the process, as there are no final results.

1. FRAMEWORK

We believe that school have today, simultaneously, the duty and the right to choose and implement the best forms to integrate, prepare and improve the quality of life of its special needs students. The conception and programming of interactive artistic environments, usually confined to the territory of contemporary artistic installations, can support the creation of informal learning environments. The new emerging aesthetic sensitivity, derived from technological ludic interaction of the imaginary of contemporaneity is expanding inclusion opportunities. This study relies on the importance of self-expression as a way of recognizing human skills such as activity, motivation, creativity, imagination and responsibility (Damásio & Damásio, 2006) and also considers the great importance of emotional intelligence (Punset, 2010). Inspired in authors such as Brooks, Hasselblad, Petersson, Gehlhaar, Azeredo and others, the focus of this project was not inability but ability. Encouraging participation and allowing reaching the maximum potential of each one, we believe that interactive artistic environments can encourage artistic expression, helping students with complex requirements develop self-awareness of their abilities, incite their optimistic identity and feeling of inclusion.

2. METHODOLOGY

This is an empirical qualitative investigation, an experimental field case study, with technological mediation. The study refers to an aim of qualitative/interpretative research with flexibility in its structure method and direction (Bogdan e Biklen, 1994; p.107). The research used participant observation to collect non-numeric and unstructured data, simultaneously based on describing and understanding processes (Lessard-Hérbert, Goyette & Boutin, 1994). We tried to respect the real research contextual field, so the understanding process grew in a poorly controlled and adaptable participant observation. The study occurred in a basic school in Coimbra, Portugal, during the 2009/2010 academic year. We involved a group of twelve special needs students from special individualized curricula. The sample included young people, three girls and nine boys aged between 12 and 17 — mostly 14 year-olds. Most students came from dysfunctional social aggregates and low socioeconomic status, with a complex development story, with distinctive and several physical, psychological and social requirements. Four of those cases stood out positively, in terms of family support. The project consisted of individual observation sessions, with an estimated duration of thirty minutes. Participants had experiences with different prototypes of interactive artistic environments, which we designed or implemented. Because it is known that special needs students usually have trouble in directing and keeping attention, we worked individually with participants.

Prototypes proposed different immersion experiences based on real-time sound and image processing, as a strategy to develop, as much as possible, students ‘skills, extending and enriching their sensory capabilities.

We aimed at implementing the multisensory approach of "ludic engagement" (Petersson, 2006) and "aesthetic resonance" (Brooks & Hasselblad, 2004) mediated by technology. During the sessions, we instigated difference of behaviours, reactions and free exploration, observing the individual expression and personality of each participant. We developed the "*Special INPUT*" concept as a key element for the artistic design and technique ideation for the project. We wanted to explore distinctive aesthetics with the poetics of interactive sound and image, creating different situations of immersive experiences based on real time abstract sound and image compositions. Apparently simple, each prototype emphasized the single input of each participant, contemplating three areas: sound, movement, and visual inputs. So, the environments are grouped into different types of action. As a process of discovery, three types of relation with the environments emerged — sound, movement and image. From these approaches we created three main prototype concepts: *Special SOUND*, *Special MOVEMENT* and *Special ME*. The word "special" highlights individuality, the focus of this project on ability instead of inability or incapacity, valuing difference and genuine expression.

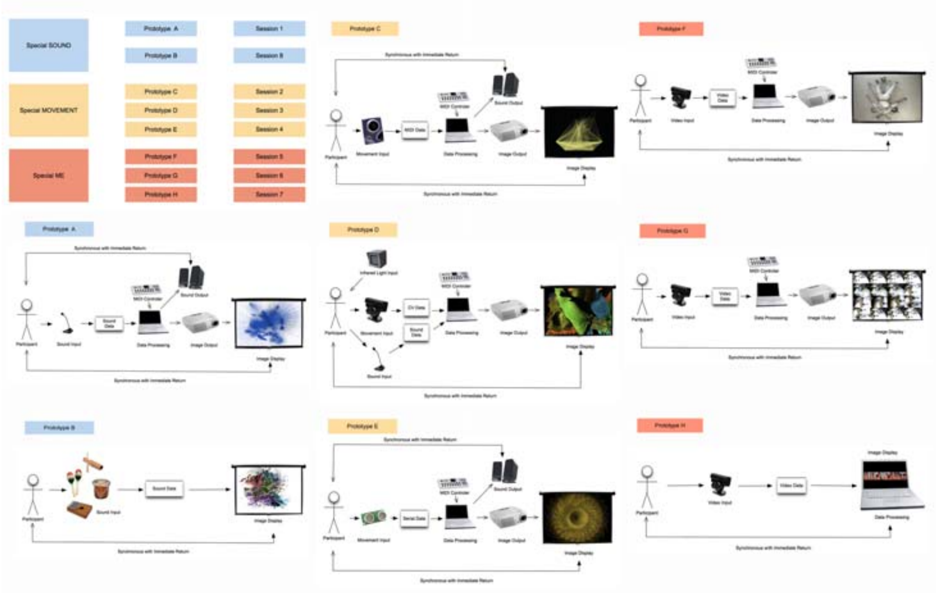

Figure 1. *Special INPUT, interaction approaches, prototypes and observation sessions' correspondence.*

2.1 Technical approach

As to the technical approach to design or implement the prototypes we used the interactive programming environment Max MSP Jitter, occasionally in communication with the Community Core Vision open source/cross-platform solution for computer vision. In one of the prototypes we also used the Processing programming language and environment. For data input we used hardware such as a microphone, an ultrasonic sensor for distance measurement attached to an Arduino board, the PlayStation Eye webcam modified with a special kit of lenses with an infrared filter, the Air-FX Hand Controlled Digital Effects and the Evolution UC16 MIDI controller. In one of the environments, we used real musical instruments as sound input. As output we used a video projector, a sound system and the computer. We programmed all prototypes with the exception of the H prototype presented in session 7 — by Golan Levin — available on video capture Processing libraries under the name *SlitScan*.

2.2 Instruments

The prototypes were the main instruments of this study and their physical and virtual interfaces were developed just enough to understand the impact of each proposal. For each prototype we contemplated the skills of the participants, considering user detection and response issues, contemplating sensibility adjustment settings. For the data collection process we used techniques that allowed the subsequent process of encoding data interpretation. Video recording with two cameras — front and rear — was an extremely prolific method for data analysis. Using qualitative data analysis software — Nvivo8 — we extracted very rich and precise descriptive narrative from videos, isolating data categories. We also used screen captures during the sessions to archive images produced by the participants. Those files were compiled and distributed to the students at the end of the sessions. During the process, to describe and reflect about them, we also used field notes, observation guidelines and analytical memos. We registered the behaviours of the participants, connecting

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them to variables of their aptitude (Bruce Tuckman, 2005). On this basis, in each session with each participant, we obtained information about intellectual, emotional, personal, interpersonal, intrapersonal, psychomotor and artistic skills of the students in those environments.

Figure 9. *Images samples of five random sessions.*

2.3 Sessions

Each session began with a short introduction and, sometimes, with a demonstration of the proposed environment, motivating autonomous participation. We presented the prototype concept to the students, indicating its function mode and aesthetic possibilities. During the action, referring ideas such as plasticity, dynamics, strength, lightness and visual rhythm or mass and temperature of sound, speech, intensity, harmony or disharmony, we encouraged students to position themselves in the environments with openness to the stimuli. Participants revealed different personalities, so we always respected their nature, listening to their wishes and recording their preferences and suggestions. We never forced students to participate; we encouraged them to stay less time in the sessions than expected, so we got sessions ranging from 10 to 40 minutes. The assiduity of participants was good, although some of them occasionally missed the sessions for different reasons — illness, visits to the doctor, forgetfulness or rejection. Out of 96 sessions we got 74 presences. Out of 12 students, four never missed a session, three missed two, one missed one, and four missed three or more sessions. We never thought that this could be a problem because this study, instead of focusing on individuals, focused on group results.

3. OUTPUTS

We do not present final results: instead we share our experience in this process. During the sessions, we got a general acceptance and enthusiasm on participation but with sporadic situations of resistance or disinterest. We had more difficulty connecting to the students who, somehow, were going through a period of great emotional instability in their lives and, occasionally, with extremely shy students, we also observed saturation mixed with reservation to participate. Some of the participants showed more difficulty to concentrate on a task. On these situations we tried to work with them, connecting and sharing participation. Some of them got really excited with the proposals: clapping, beating their feet on the ground and singing loudly in *Special SOUND* setups; exploring their bodies in multiple ways, sitting, standing, running, jumping, spinning, in *Special MOVEMENT* setups; and interacting with their self-images and appearance in *Special ME* setups, working their identity through self-portrait, using a webcam to film themselves freely — changing the view plan or subject and discovering the visual impact of video effects like colour and contrast. Participants were extremely different, so we got diverse reactions. For example, one of the students refused to participate except for in Special *ME* environments — session 6, prototype G — and she just gave us her true attention when she found interest interacting with her own image, by capturing live video. On the other hand, a student who had more difficulty co-ordination physical equilibrium overcame motor constrictions exploring tirelessly each environment and staying in sessions, in most cases, beyond the time stipulated. During the observation process, considering intellectual skills of the students, we documented easiness in understanding the environments, interfaces and different kinds of interaction, discriminating images and sounds. We tried to perceive the attention of the students — maintenance, division and alternation — through their attitudes and development of their own interaction methods. Students could explore image settings such as colours, black and white, brightness, transparency, saturation or contrast, and they could switch sounds. We recorded their preferences and talked with them about those experiences. We could perceive their intentions, appreciating to see the resulting images, wanting to save them, demonstrating interest in their own work and giving us a positive feedback. On emotional skills, we wanted to observe the interest and involvement with proposals, and the facility to adapt and regulate their reactions to the context. Behaviour was not an easy fit for a student who was always very excited and anxious as well as two others who showed some apathy, preferring to talk about other things. However, in most cases we perceived satisfaction from their smiles and laughter and their constant search for feedback. On personality skills, we noticed curiosity, excitement, persistence and cognitive flexibility to setup interaction challenges. Most students accepted and adapted to all proposals, even when they were so different, coming freely to fruition. On interpersonal and intrapersonal skills, we observed approval of the project, with a certain fascination. In most cases, participants arrived at and left sessions with a positive attitude. We believe we witnessed moments of great self-confidence and autonomy, in some cases interspersed with fears and lack of self-confidence in their own

actions. Whenever we could, we positively reinforced performance, increasing self-confidence, self-esteem and self-concept of participants. On *Special ME* setups, collaborative interaction increased by the live video potential, emphasized communication opportunities to give feedback to the students promoting more evident self-confidence. On psychomotor skills, we felt that for some of these students there was a great opportunity to demonstrate physical skills of which they became proud — such as pirouettes, ball tricks, imitation of voices — increasing the feeling of inclusion, and also as a way to overcoming physical requirements and motor constrictions with joy. And as we were not asking them to use a specific physical ability, they could value and use whatever they had in them to express themselves. And this was the same with artistic skills: we just valued the individual expression of these students to explore sound and image, identifying different exploration methods and sensitivities.

4. CONCLUSION

As another artistic layer for self-expression we believe on the holistic development of the individual in these contexts, where special needs students can exceed their own obstacles, exploring and taking advantage of them. The project allowed different experiences with the self, which we consider extremely important, mainly for special needs students who, for different reasons, do not have access to all kinds of inclusion opportunities. We observed different students, on very different situations, in different immersive audio-visual contexts, so we acknowledge the subjectivity of this study. Nevertheless we saw these people express themselves freely and having fun. Their motivation and participation was rewarding, especially when we used positive reinforcement to convince them to explore the environments, especially after seeing those young adolescents exceed themselves, identifying their skills through those environments. Communication opportunities were also of great benefit. We were connecting and knowing each other. At the end, the students truly appreciated keeping their sessions recordings, sharing them proudly with colleagues, tutors, friends and family.

About prototypes implementation, *Special SOUND* and *Special MOVEMENT* environments offered interaction with multimedia events, like images, 3D or 2D graphics and sounds, prepared by us. In the future, with technical resources and an appropriate time line, it should be very interesting to engage students in the design process of these prototypes — feeling the experience of photographing, recording sounds, and even programming for some of them. The enthusiasm with *Special Me* environments is probably connected with the major role of the participants in those environments. Nowadays, interactive technologies symbolize a lot of enthusiasm for young people. Working with this group, in a poetic way with abstract goals, showed us that we can use interactive technologies as a way of promoting free self-expression, self-knowledge and help work on a positive idea of the self. If we promote society confidence on the abilities of these students, they will feel that what they do is valuable and, consequently, included through their expressive abilities.

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Generative design as a method to foster explorative behaviour in virtual motor rehabilitation

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ABSTRACT

The article contrasts the bottom-up with the top-down approach to the development of systems for virtual motor rehabilitation. A research project is presented that uses the top-down approach for the development of a system for virtual neurorehabilitation of amputees suffering from phantom limb pain. Artistic visualisations that are inspired by the field of generative design will be used to constitute the illusion of a moving phantom limb. The coupling between the movements of the patients and the visual effect is not straightforward but needs to be discovered through explorative behaviour. It is assumed that this will help the patients to concentrate on the treatment and therefore a strong therapeutic effect will be achieved.

1. INTRODUCTION

Since the advent of affordable motion capture systems – e.g. the Nintendo Wii Controller and the Microsoft Kinect/Primesense sensor – the application of Virtual Reality technology for motor rehabilitation is becoming increasingly popular. The technology serves a variety of purposes (Burdea, 2003), of which one of the most prominent is the motivational benefit. A number of therapeutic approaches have been reported to benefit from the integration of video game components in the therapy session (e.g. Cameirao et al., 2009; Holden, 2005; Prange et al., 2008; Pyk et al., 2008) and it is stated that the patient's compliance may be improved due to the entertaining nature of the virtual environments (Flores et al., 2008; Lange et al., 2009). Therefore in virtual motor rehabilitation the technology plays a central role for the effectiveness of the treatment and designing the virtual environment is a crucial step in the development of the therapy. Approaches towards this goal can be classified into two poles: bottom-up design and top-down design.

2. DESIGNING SYSTEMS FOR VIRTUAL MOTOR REHABILITATION

The bottom-up approach to the development of a system for virtual motor rehabilitation can be described as follows: an established therapy setting is transferred into a virtual environment and enriched with game components. The patient e.g. controls an avatar with his/her natural movements and reaches for targets or collects items in the virtual world. The game components are placed such that the patient needs to perform therapeutically relevant movements to accomplish the task. The therapeutic setting and the expected outcomes are defined through the established non-digital therapy. The bottom-up approach makes use of the virtual environment in ways that are naturally (physically or technically) conceivable in the real world. Thus it focuses on a close relation between the displayed elements (environments, avatars or objects) and their real world counterparts and encourages natural behaviour in or with these elements. This approach benefits from intense communication between the development team and the clinicians to include the practical experience with the established therapy. When using a modular software architecture iterative development is possible and early user tests can be performed in realistic settings to ensure continuous improvement of the system.

On the other hand, the development may also follow a top-down approach: for the design of the virtual environment the intrinsic properties of the digital medium are considered prior to the adaption of established therapy settings. The starting point for the development is the abstract description of the system: three-dimensional, temporal data (e.g. body posture or gesture) will be transformed according to predefined rules into real-time visual feedback. This way the reaction of the system to the patient's movements may be generated in various ways based on algorithmic transformations. Possible underlying rules for these

transformations are then explored to meet therapeutic goals. Emphasis is put on the innovative application of the technology for motor rehabilitation and this approach benefits from a loose focus on established settings. Inspiration may be found in artistic fields like media art or computer game design. A relatively advanced prototype will be needed before beginning with user testing when the system is not closely integrated with the established processes.

Though the bottom-up process has many benefits in terms of the integration in the clinical practise it may be difficult to put forward abstract or artistic ideas. In this article it is argued that the top-down approach is valuable for the development of innovative systems that lead to therapeutic treatment not possible without the technology. In the following section a research project is described in which this approach is applied to develop a new system for virtual neurorehabilitation of amputees. Along with this, the development environment and a middleware library are introduced, which can be used for similar research in this field.

3. GENERATIVE DESIGN FOR THE TREATMENT OF PHANTOM LIMB PAIN

3.1 Research project

The aim of the research project is to develop a system for the treatment of amputees with phantom limb pain. The system makes use of the principles of mirror therapy (Ramachandran & Altschuler, 2009) and it explores the application of artistic visualisations for this purpose. The patients will experience the illusion of controlling the system with their phantom limb. However, instead of using two virtual arms that move according to the movements of one arm of the patients – which would be a bottom-up adaption of the established mirror therapy – artistic visual output is displayed that gives the impression of being controlled by symmetrical movement of two arms. This output is generated through algorithmic transformations based on the recorded movement of the patients and these algorithms are inspired by the field of generative design. It is assumed that the system allows for an engaging experience and that the interaction with it will help to concentrate on the virtual environment, contributing to a strong illusion of a moving phantom limb. Furthermore, the reaction of the system to the patients' movements is not straightforward. Rather, the coupling between motor actions and visual feedback needs to be discovered through explorative behaviour in relation to the external effect. Fostering explorative behaviour while focussing on external effects can be beneficial for motor learning, as research in sport science has shown (Schollhorn et al., 2010; Wulf, 2007). Figure 1 shows an early prototype of the system that is currently under development.

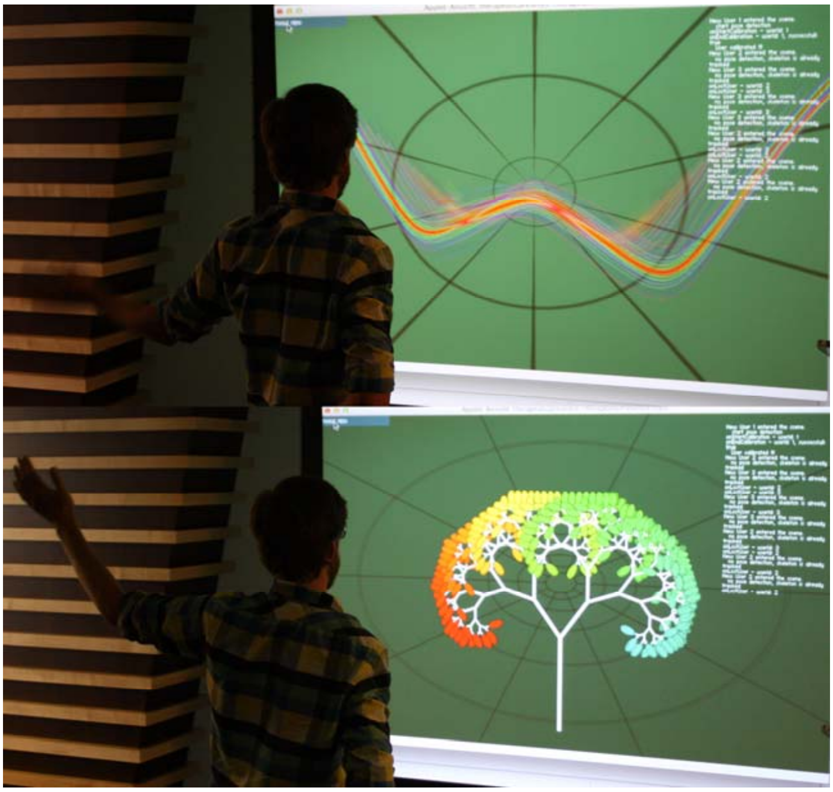
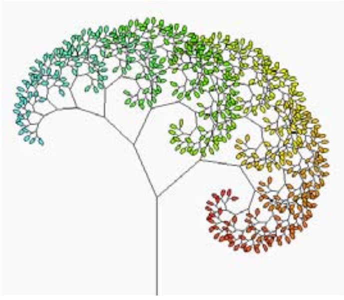


Figure 1. *A system for virtual rehabilitation of amputees suffering from phantom limb pain*

3.2 Generative Design

The field of generative design inspires the algorithms that generate the visual output of the system. In media art the method of transforming data algorithmically into expressive (visual) output is known as generative art or generative design (McCormack et al., 2004). John Maeda and Paola Antonelli describe this idea as the challenge to "discover the intrinsic properties of the new medium and to find out how the stroke you can 'draw' via computation is one you could never draw, or even imagine, without computation." (Maeda & Antonelli, 2001, p175) In interactive generative systems the elements that form the output are not shaped or constructed prior to the interaction but rather generated during and as a reaction to it. Thus no two experiences with the system will be the same. Only the rules that generate geometric forms, colours and transitions are predefined and given in form of algorithms. This way the input data defines the output. Artwork and research on generative design have found a large set of algorithms demonstrating the vast amount of variations that are possible (Bohnacker et al., 2009). To give a simple example, figure 2 shows a two-dimensional tree and the generating algorithm.



```
branch (length, count)              // branch() is called recursivly w/
  length *= 0.7                     // gradually decremented parameters.
  count -= 1                        // length defines the drawing of
  if (count > 0)                    // the line of the branch, count
    rotate(angleLeftArm)            // defines the number of branches.
    line(0, 0, 0, length)           // resetToOrigin() undos the prior
    translate(0, length)            // rotation and translation
    branch(length, count)           // angleLeftArm and angleRightArm
    resetToOrigin()                 // are calculated outside this
    rotate(angleRightArm)           // function
    line(0, 0, 0, length)           // The line for the trunk is drawn
    translate(0 ,0 , 0, length)     // before calling branch() for the
    branch(length, count)           // first time
```

Figure 2. *A tree and its generating algorithm*

When natural movements are used as input data, algorithms can be developed that transform expressive behaviour into aesthetic visualisation. For the application of generative design in virtual motor rehabilitation the definition of expressive behaviour in terms of the therapeutic goals is important. Biomechanical descriptions of the therapeutically relevant movements can be used to define body postures and gestures that are used as input data. These descriptions are given by kinesiology (Neumann, 2010).

3.3 Processing IDE

For working with generative design the Processing IDE (see www.processing.org) has become popular. It is based on the Java programming language and provides a framework and simplified syntax for the creation of software. The IDE and the framework were created to give artists and designers with little programming knowledge a tool to experiment with generative design. It focuses on rapid software prototyping in order to enable the designer to produce output and variations in an easy and fast manner. One of the strengths of Processing is its large community. Developers provide a growing number of libraries, tutorials and open source examples to build new software on and to use hardware components through programming interfaces (e.g. the Microsoft Kinect/Primesense sensor). This makes Processing an ideal environment to experiment with the top-down approach towards the development of systems for virtual motor rehabilitation.

The software that is developed for this research project is build with Processing and it is publicly available under the following link. A library that gives access to the posture and gesture of the patient is separately available to be used in similar research projects (see http://github.com/thschuel/).

4. CONCLUSIONS

In this article the top-down approach to the development of systems for virtual motor rehabilitation was proposed. With this approach innovative systems may be created that explore the possibilities of the digital medium for therapy. It was argued that artistic visual output may be used to foster explorative behaviour of the patients and that this helps concentrating on the treatment. Generative Design was introduced as a method to create this kind of output. Furthermore a research project was described that demonstrates this idea. The software for this project is developed using the Processing IDE and a middleware library is available for download to aid similar research. The design of the virtual environment plays a central role for the effectiveness of virtual motor rehabilitation applications and therefore exploring this approach may be valuable for other applications, too.

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Virtual office for students with learning difficulties

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ABSTRACT

People with learning difficulties often face lack of opportunities in their everyday lives, and less than 10% of them have a job (Brown et al, 2010). This group needs additional support and innovative pedagogical approaches, matched to their needs, to develop skills for work and independent living. We developed a virtual office for students with learning difficulties, which teaches them how to get their first identity or national health insurance card, passport and European health insurance card. In this paper we address questions related to the design and evaluation of games developed to suit the needs of people with individual learning needs.

1. INTRODUCTION

1.1 Learning difficulties– national situation in Hungary

In Hungary, the number of people with learning difficulties (2001 census data) is 56,963. Unfortunately only a small number of this group is working actively. 2001 census data shows that 7% of the learning difficulties were employed, 1.2% were unemployed, 47.2% of them were inactive wage earners and 44.6% of them were dependents. Nearly 14% of the active working society (aged 18-64) has a sort of work-limiting illness or disability in Hungary. This means nearly 750,000 people receive some kind of care, and only less than a quarter of them is in employment. Approximately 140,000 people of the group want to work but cannot find a job. The current system gives a state-subsidized or a fix job for only 30-40 thousand people. (Institute of Budapest, 2011). This is a huge disadvantage not only to disabled persons, but to the whole society and to the economy too. In Hungary, many people with changed working abilities live on some kind of pension benefits, who actually belong to the working-age population. This produces a big burden for the National Health Service. Our goal is to reduce identified skills gaps of the target group and to increase the number of our people from the group of targets entering the labour market.

1.2 Serious games

Computer games have the capacity to take learning to a whole new level. Playing computer games has become one of today's most popular media activities for people of all ages. Virtual Reality (VR) games are popular among children and young people all over the world. “The current global player population of the three games(selected out of dozens) that was studied over the past few years (Lineage I, Lineage II and Word of Warcraft) totals over 9.5 million - a population which rivals, e.g. most US metropolises” (Steinkuehler, 2006). “The computer gaming industry has now surpassed the “Hollywood” film industry in total entertainment market share, and in the USA sales of computer games now outnumber the sale of books.” (Lowenstein, 2002) (Doug Lowenstein, President, Interactive Digital Software Association)

If we search for the phrase ”serious game “ on the internet we get more than 97 million results in only 0.27 seconds. This shows that serious games are increasingly popular (Sik Lányi et al, 2010). There are several definitions of serious games (SGI, 2012; Arnab et al, 2012), but all agree that serious games or persuasive games are computer and video games used as persuasion technology or educational technology. They can be similar to educational games, but are often intended for an audience outside of primary or secondary education. Serious games can be of any genre and many of them can be considered a kind of edutainment [8].

1.3 Usability

Part of Game User Research and Game Usability Testing focuses on the user’s interaction with the game to identify any issues that hinders their use, along with their objective solutions. Usability is about maximizing

effectiveness, efficiency and satisfaction. This definition originates from the productivity software industry, but it is also true for game design. In games, usability is about delivering a better and deeper experience with fewer problems, interruptions or challenges that are not a part of the game (Bandura, 1994). Today, game design also involves a focus on traditional usability such as creating clear terminology as well as non-intrusive, easy-to-use user interfaces (Bandura, 1997).

While many new technologies have become available for research and education, many fundamental problems remain to be addressed by informatic research. We hope that the number of investigations conducted in the field of serious games, Virtual Reality application for special needs education will grow. Computer graphics are better now and the 3D rendering techniques are becoming more mature, thus contributing to the reality look of the simulated environments (Sik Lányi et al, 2006).

2. DEVELOPING METHOD

Around 10 serious games were designed and developed under the EU Leonardo Transfer of Innovation Project: Game On Extra Time (GOET, 2012). The project supports people with learning difficulties and additional sensory impairments in getting and keeping a job by helping them to learn, via games-based learning; skills that will help them in their working day. These games help students to learn how to prepare themselves for working, money management, travelling independently etc. The idea of developing an office simulation came from the GOET project. One of the games developed within the frame of the GOET project was the “3D Work Tour” game, which simulates the first days at a workplace. A teacher, in the Kozmutza Flora Special School suggested developing a similar game to simulate the official process of getting the four kind of document. The skills to be developed via this game were defined by the teachers at the school.

The program was created in Adobe Flash with Action script 3 support. For processing data it uses XML support. As the result of its platform-free feature it can be used on different operation systems. The avatar was made with Poser. The office furniture was modelled with Maya.

The administration in the Office of Government Issued Documents, the different official written proceedings and related tasks produce serious difficulties for the mentally impaired students. For this purpose we have constructed the Virtual Office of Government Issued Documents program which allows the filling in of four kinds of document applications. The virtual people and the office are similar to the real office found in Veszprém, our home town. This feeling of reality can motivate the user of the games to play more; and the more students play, the more they practice the tasks they will encounter in the real world.

Figure 1 shows the main menu of the game, Figure 2 shows the payment at the post office, Figure 3 shows the waiting time for the number in a queue and Figure 4 shows making the photo.

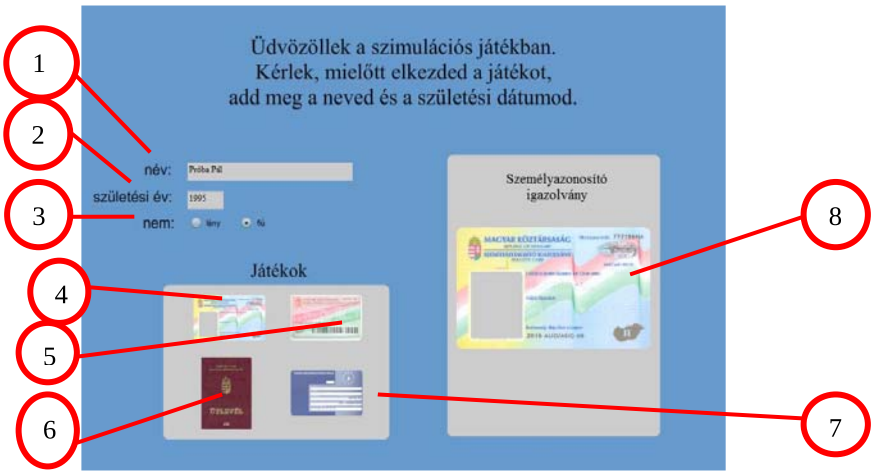

Figure 1: *The main menu of the game.*

Starting the program, the player has to give her/his name (1), date of birth (2), and sex (3) on the main screen. If the user moves the mouse over a button shown in the lower left corner of the screen -depicting the identity card (4), the address card (5), the passport (6) the European health insurance card (7)-, she/he can see the enlarged card in the frame shown on the right side of the screen (8). The user can start a type of the games by clicking on one of the previously mentioned buttons.

Figure 2: *At the post.*

In the post office the player can pay the fee. The user can see her/his money in the frame, which symbolizes the purse (1). The student gives it to the officer by clicking on each denomination. The information panel is under the virtual purse (2). On the panel the user can see the amount, that should be paid, and the chosen amount to be handed over. If the paid amount reaches the fee, a button (3) appears on the panel, which is for handing the money over. After paying the cheques successfully, the student can go back to the Virtual Office of Government Issued Documents with the „Vissza az Okmányirodába" (Back to the office) button (4).

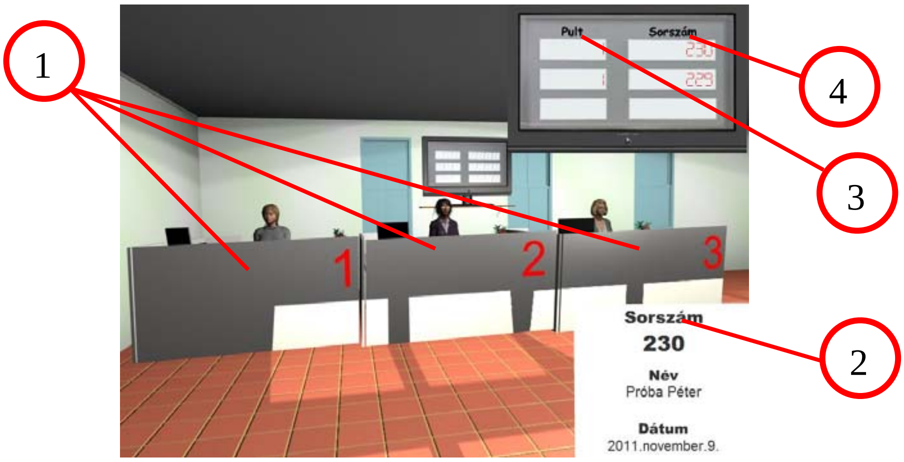

Figure 3: *Waiting for the number.*

After the clerk has given a number to the player, stepping in the administration room the user has to choose the counter from the three counters (1) according which of them calls his/her number (2). On the large screen the counter (3) and the called number(4) can be seen.

Figure 4: *Making the photo for the ID card or passport.*

After selecting the proper counter, the player arrives to the administrator (1), who asks usually for the presented documents shown at the beginning of the game (2). These documents are displayed on the screen (2). The player passes them by clicking the documents. For the new ID card and for the passport a photo is needed. If the user is called upon to do so, the next step is by clicking on the "I go into the booth (bemegyek a fülkébe)" button (3).

3. TESTING THE "VIRTUAL OFFICE" GAME

The pedagogical and usability testing was based on the others games' testing process of the GOET project (Sik Lanyi et al, 2012). The pedagogical testing has run for 5 weeks. Every week students played the game twice for 20 minutes. Later the teachers wrote case studies about each student. The usability testing was based on a questionnaire with 40 questions. The game was tested by 15 intellectually disabled students. Both the students and the teachers liked the graphic realization. Overall, the user tests made by the students show, that this is an enjoyable and easy to use game. It is important; the teachers' opinion met the quality requirements of the game.

4. CONCLUSIONS

In this paper we have discussed the design and evaluation of the "Virtual Office" game and its user interface. This game was developed for students with learning difficulties to help them in activities of daily living, in their working life and specifically in the process how to get their first identity cards, national health insurance cards; passports and European health insurance cards. As a final result, a successful game was created to help them getting over handicaps and getting integrated smoothly into the society. The Virtual Office was tested in the Kozmutza Flora Special School in Veszprem.

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Developing serious games for victims of stroke

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ABSTRACT

This study introduces Serious games, which are special games planned within the "StrokeBack" project. The aim of these games is to support the rehabilitation process of stroke patients who have upper limb impairments and damaged psychomotor abilities. In this paper we will present the methodology and ideology of Serious games, and we will prove the importance and necessity of developing such tool.

1. INTRODUCTION

Each year more than 700,000 people in the United States suffer a stroke, making it the third most common cause of death, especially for older people (NINDS, 2011). Incidence in Europe is similar, about 2 million people per year. According to the World Health Organization's data 15 million people suffer stroke worldwide each year. Although survival rate is improving, 5 million die and another 5 million remain permanently disabled (TISC, 2012). Our societies are facing a growing number of people aged at least 75, many of whom will experience impairment or disability, due to stroke. This older population will rise from 7.5% of the European population in 2003 to 14.4% in 2040, i.e., almost double. Effective rehabilitation is critical to reduce the burden of disability not only on the individuals and their families, but also on society.

Within 'StrokeBack', a newly started project funded by the EU, our goal is to improve the quality and rate of stroke recovery. Changes in clinical practice mean that most patients are discharged from hospital within one or two weeks; we are therefore focusing on home-based rehabilitation. There are many advantages to this approach; for example new skills are automatically transferred into daily life, improving motivation and morale. In addition, home-based therapy is less expensive. The architecture and rehabilitation cycle of the StrokeBack project can be seen on Figure 1.

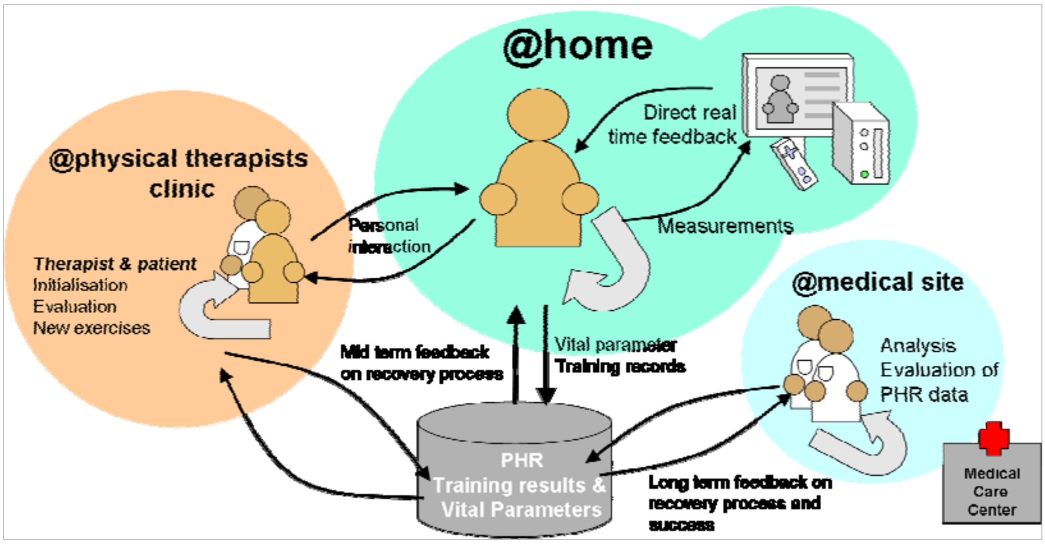

Figure 1: *The StrokeBack Rehabilitation Cycle.*

Recovery of voluntary motor control is enhanced by many repetitions of functional exercises incorporating fine finger and whole arm movement. The aim of this part of the project is to create games that enable the patient to do these exercises 'playfully'. The proposed games not only target recovery of sensory motor control, but to improve their logic and thinking abilities too.

We are planning to develop a few types of games, for example, a labyrinth, a free-kick game, a break the bricks game, virtual piano game etc.

2. SERIOUS GAMES

The target public of the Serious games are patients with upper limb impairments, which was caused by stroke. Because the games are controlled with a mobile phone, which the user has to hold in the damaged hand, we must assume that the patient is able to do it.

The planned games are single player games, which the patient can play with by himself/ herself. After installing and setting up the software, the patient can use it alone; the therapist won't need to assist. This can be very convenient because the user can play at any time, and won't need to wait for the appointment with the therapist, and this may result that the patient will play more with the games.

2.1 Architecture

The games use the architecture shown on Figure 2. The games run on a PC, which can be controlled with a mobile phone. The mobile phone is connected to the PC with WiFi, and using TCP as a connection protocol. With the phone's accelerometer and orientation sensor the patient's movement can be detected. This movement data is processed by the phone, and sent to the PC via WiFi.

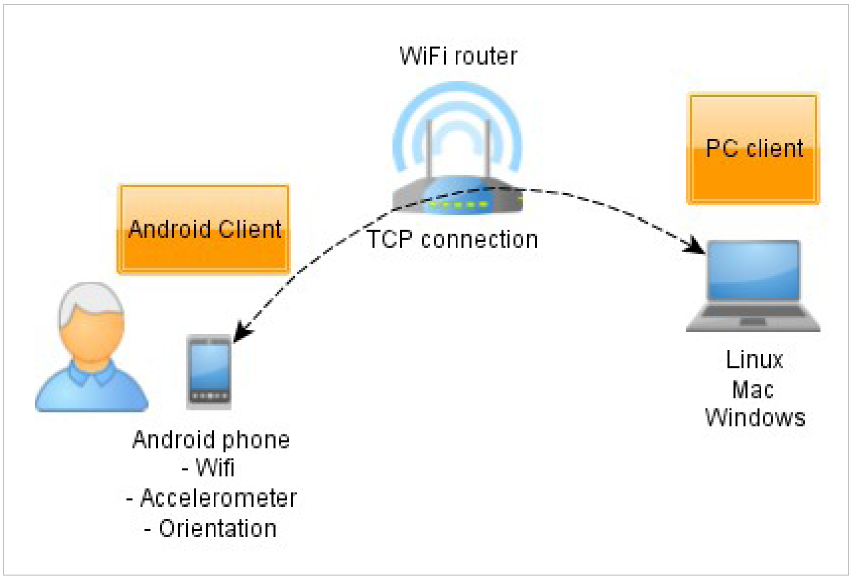

Figure 2: *The architecture diagram of Break the Bricks.*

2.2 Control

The user can control the games by moving the phone, and these precise arm movements are the rehabilitation exercises. The patient holds the phone in the damaged arm's hand, and depending on the game he/she controls the game with whole arm movements, or with flicks. The phone will detect the movement of the hand with its built-in sensors, and after processing this and converting to coordinates it sends it to the PC via WiFi. The PC will work this data and adapt it to game movements.

The patient needs concentration and the games are challenging and pleasurable. These attributes combine enjoyment with exercise, enhancing the rehabilitation process. The patient is also motivated by variations in the levels of the game, which can be raised by breaking his or her own high scores. Also an advantage of the game is that it uses the built-in accelerometer of the phone and relies on the patient's balancing ability, so this capability can also be challenged.

There are many advantages of using a mobile phone with Android operating system. First of all mobile phones and smartphones are now widely used all over the world, so it is very easy to provide (and many of us

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already has one). It's also good to use a phone for controlling if the patient has already used one before the stroke, because it can be difficult to learn the usage of a new device (Charters, 2012a). And on the other hand, smartphones can be used for other rehabilitation purposes, so the patient won't need to purchase one only for game therapy intention (Charters, 2012b). Another advantage compared to gesture recognition and computer vision controlled systems, where the patient has to stay and move within the range of the device, which can be very frustrating, is that the mobile phone doesn't have any limitations like this (Rand et al, 2004).

We chose Android OS because it is independent from the mobile phone brands, so the patients won't be restricted to use a given brand or phone type.

2.3 Development

The games are developed for the Android operating system, because this platform is frequently and widely used among mobile phones and smart phones, making it easily accessible. The mobile phone's Android application is written in Java. The PC program is written in Qt, which is a C++ based cross-platform framework, so it can be used irrespective of the PC's operating system or configuration. Qt is also good because it's widely used, open source and has a great support (Summerfield, 2010).

2.4 Virtual reality

Virtual reality is very important part of the game, but not in the conventional form. The users will see a 3D environment, for example the corridors of a labyrinth, which they can move in virtually, by moving the mobile phone. In this virtual environment, they can play with games, such as a brick breaker game, a memory game, a free-kicker soccer game, or a logical pairing game. During the game, the patient's movements are detected in 3D by the mobile phone's built-in sensors, making movements feel more 'real'. This feeling of reality can also motivate the user of the games to play more, and the more the patient plays, the more exercises are done, and the key of the rehabilitation are these exercises.

On the other hand, the virtual environment can be confusing and hard to understand for some patients. For this reason, we must aim for an easily understandable and usable user interface to unburden the usage of the games. This is also very important because the patient will use the software alone, and he/she needs a user-friendly environment to do this.

The patient's movement data, high scores, the exercises practiced by the patient, the degree of the recovery and much more data will be stored in a database. The information following from this huge set of data helps the medical attendants and stroke professionals to improve the rehabilitation process of stroke patients.

3. RESULT

Since our games are only in the developing phase, we didn't have much opportunity to test the effectiveness of the therapy supported by them. We had some inchoate testing with two stroke patients, to see the usability and intelligibility of the half-ready software. From this experience we got much information regarding the graphical user interface, which helps us to make the games more user-friendly.

Also we searched the related literature to see the impact of rehabilitation with video games, and found that there are some approaches that prove the efficiency of rehabilitation with games. Virtual reality and other video games can significantly improve motor function in stroke patients, according to research from St. Michael's Hospital. Patients who played video games were up to five times more likely to show improvements in arm motor function compared to those who had standard therapy (St. Michael's Hospital, 2011).

4. FUTURE PLANS

After testing the games with a mobile phone, we would like to draw the conclusions, and consider using other controller devices like Microsoft Kinect or sensors attached to the patient's arm. With these devices, more or rather different type of movements can be detected, so there is a possibility that other type of games will be needed to cover these motions.

Another plan is to make some multiplayer games, where the patient can play with other patients, or with the therapist or a caretaker person. Playing together with someone facing the same problems can be

motivating, and also playing with friends and family is fun and a good opportunity to cheer up and hearten up. For these we plan to use Microsoft Kinect as a controller device.

5. CONCLUSIONS

These games are potentially useful ways to enhance recovery of motor control following stroke, because while playing them, the patients will do small, entertaining, but important exercises. Most people like to play games, so the boring activities can be made entertaining and pleasurable.

Positive outcomes of the participation of people with disabilities in research and development of serious games have been demonstrated (Bühler, 2001; Brown et al, 2010).

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Virtual reality and brain-computer interface for joint-attention training in autism

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ABSTRACT

Autism Spectrum Disorders (ASD) are characterized by three core behaviours: deficits in social interactions, in communication and repetitive and restricted behaviours. One of the pivotal skills we acquire for social interaction is joint attention, which has been also related to communication skills. The systemizing theory of Autism suggests that these individuals have a preference for computerized systems because of its structure and deterministic functioning. It is hypothesized that Virtual Reality may play an important role for teaching social skills in these individuals, since it can mimic the real world in a more controlled way. In this paper, we propose the use of VR for the training of joint-attention skills in Autism using a Brain-Computer Interface. We developed environments where a virtual human character directs attention to a virtual object in the environment, which the user is supposed to identify by paying attention to it. The subject's brain activity is monitored in real time by electroencephalogram (EEG) and a classifier tries to identify the target object detecting the P300 wave in the EEG. Preliminary results show a classification accuracy of 90% encouraging the approach.

1. INTRODUCTION

Autism Spectrum Disorders (ASD) are neurodevelopmental disorders characterized by a triad of core symptoms: (1) deficits in social interaction, (2) deficits in communication and (3) repetitive and restrictive interests and behaviours. The main deficits in autism are related to social interaction. Children with ASD avoid human interactions and present a low level of social attention (American Psychiatric Association, 2000). ASD prevalence has been reported with an increasing incidence in the world. However, ASD prevalence estimations vary among studies. In the United States of America, Autism and Developmental Disabilities Monitoring (ADDM) Network from the Centers for Disease Control and Prevention (CDC) have conducted systematic studies for the last decades (Report, 2012), which identified an increase from 1 in 150 in year 2000 to 1 in 88 in year 2008 (about 1% of the population). These studies have a periodicity of 2 years and cover a total of 14 sites along the USA.

Joint attention is a social interaction in which two people use gestures and gaze to share attention with respect to a third object or element of interest (Charman, 2003). It involves the ability to gain, maintain and shift attention. Joint attention seems to be related to communication as a requirement for its development. Interventions that rehabilitate joint attention have shown correlated improvements in the communication skills of the children, such as social initiations, positive affect, imitation, play and spontaneous speech (Kasari et al., 2006).

Virtual Reality (VR) is a term that applies to computer simulations that create an image of a world that appears to our senses in much the same way we perceive the real world. For that, several technologies are used to stimulate our senses, from stereoscopic displayers to haptics with force feedback. The application of VR in Autism is motivated by several reasons, especially for providing the possibility to simplify the reality to a level tolerable for the individual (Bellani et al., 2011).

A Brain-Computer Interface (BCI) - also called Direct Neural Interface or Brain Machine Interface - is a direct pathway between the brain and an external device. The idea is to interpret the brain waves in order to allow communication through the simple thoughts of a person (Farwell and Donchin, 1988). There are several variants of BCI. We use in this project the P300, which is a neuronal response for an infrequent stimulus. It is elicited by an oddball paradigm, where an infrequent target stimuli appears between frequent non-target ones. When this happens, a positive fluctuation of EEG signal appears 300 milliseconds after the presentation of the target stimulus - the P300 event-related potential.

In this study we propose the combination of realistic VR stimuli with a P300 BCI to evaluate the cognitive detection of joint attention stimuli in Autism. The BCI approach aims to verify if autistic subjects preform differently in a cognitive task involving social processes.

2. SYSTEM

For the development of the system we created two main modules: one for the EEG signal acquisition and processing and the other for the generation and rendering of the virtual environments. Fig. 1 shows the architecture of the system.

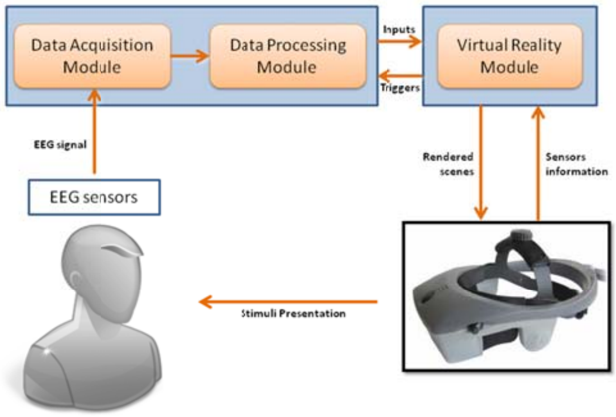

Figure 1. *System architecture showing the Data Acquisition and Processing modules developed in Matlab and the Virtual Reality module developed in WordViz® Vizard. The system is a close cycle of neuro-feedback where the responses captured in EEG are sent to the VR module where are used for the stimuli.*

The Data Acquisition module is responsible for capturing real time EEG data that is recorded using BrainProducts® actiCAP system with Remote Data Access. The trials are segmented (each segment corresponds to 1 second of EEG starting from the stimuli presentation) and then passed to the Data Processing module. Here, the segments are filtered for the range 0.1-30Hz and classified as target or non-target stimuli. The response is passed to the Virtual Reality module through TCP/IP. The VR module incorporates that information in the rendering on the next stimuli. Data Acquisition and Data Processing modules were implemented in Matlab while the Virtual Reality module uses WorldViz® Vizard framework. The VR displayer used was a WorldViz 3D PowerWall, combining a stereo projector with a PPT – Precision Position Tracker system, for responding to head and position movements in the VR environment.

3. VIRTUAL TASKS

We developed two tasks to explore joint attention, based on the normal process of joint attention interactions. We catalogued them as (1) identify joint attention clue and (2) follow joint attention clue.

In the first task, the user is asked to pay attention to the subject that performs a joint attention clue (like pointing, leaning or gazing somewhere) in the middle of a small crowd of virtual human characters. The objective is to check whether the users are available to detect attention clues in order to follow them. For the task to elicit a P300 ERP, each character makes a movement at different instants. Fig. 2 shows an example of this task.

Figure 2. *Identify joint attention clue task - One on the virtual characters perform a joint attention clue while the others perform non-social movements.*

In the second task, only one virtual character is in the scene, but he direct the attention (through an attention clue) to one of the objects in the scene. The user is asked to pay attention to the object indicated by the virtual human character. For the task to elicit a P300, each object's illumination is augmented at different times. See Fig. 3 for an example of the task.

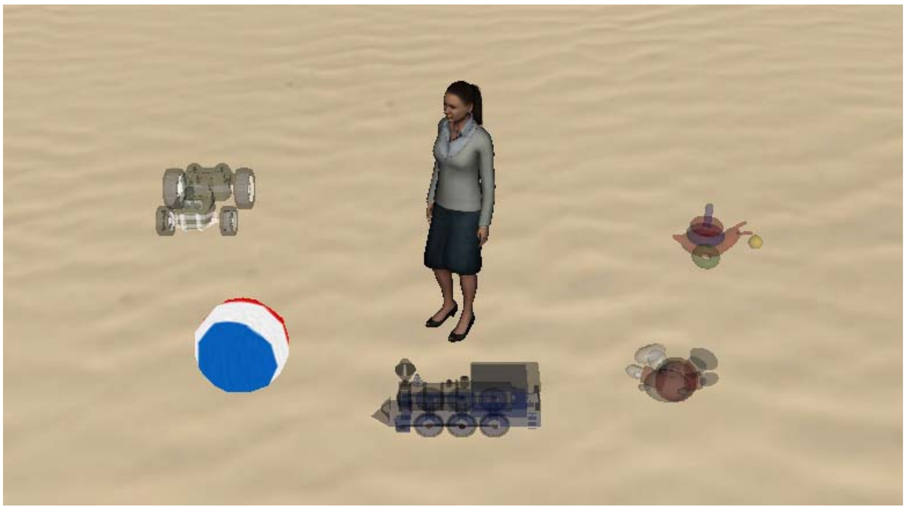

Figure 3. *Follow joint attention clue task - The virtual character directs its attention to a specific object (the ball, in the example) and the user must follow the clue and pay attention to that object.*

4. P300 CLASSIFICATION

For the classification of P300 ERPs in EEG we developed a 2-class Naive Bayes classifier. The Bayesian classifier is based on the estimation of the probability of choosing class C given n features F, using

$$p\left(C|F_1,\ldots,F_n\right)=\frac{p\left(C\right)p(F_1,\ldots,F_n\mid C)}{p(F_1,\ldots,F_n)} \tag{1}$$

where p(C) is the *à priori* probability of the class and *p(F1,...,Fn|C)* is the likelihood of belonging to class C. Because *p(F1,...,Fn)* is independent of the class, it can be ignored. Assuming the conditional independence of the features, the formula in (1) can be derived into

$$p\left(C|F_1,\ldots,F_n\right)=p\left(C\right)\prod_{i=1}^{n}p(F_i\mid C) \tag{2}$$

Assuming that the features follow a Gaussian distribution, the likelihood function can be defined as

$$p\left(x=v|c\right)=\frac{1}{\sqrt{2\pi\sigma_c^2}}e^{-\frac{(v-\mu_c)^2}{2\sigma_c^2}} \quad (3)$$

being μ_c the mean and σ_c^2 the variance of feature x in the class c.

5. PRELIMINARY EXPERIMENTS

For proof-of-concept purposes, the system was tested using 4 subjects with no developmental disorders, with mean age of 22 (std = 3). The subjects performed the two tasks while the EEG was being recorded by BrainProducts® V-amp using 16 electrodes at a frequency of 1KHz. The classification was performed offline.

Before passing the data to the classifier, each epoch was filtered using a band-pass filter in the range 0.1-30 and then down sampled to a factor of 25, passing from 1KHz to 40Hz. The channels were concatenated to generate the feature vector of size 640.

For the **single-trial** classification, the dataset was randomized with all subjects and segmented with 70% of the data for training and 30% for testing. This process was repeated 30 times.

Results yield mean classification accuracy on the test set of 89%, with specificity of 91% and sensitivity of 45%. The low result on sensitivity is mostly a consequence of EEG low signal-to-noise ratio, which reduces the sensitivity of the classifier, especially with single-trial. This results are encouraging, proving the viability of the approach and motivate the development of more robust classification and signal processing models to increase classification rates for an online application.

6. CONCLUSIONS

A new paradigm for P300 was successfully developed using high-level social animations performed by virtual characters. P300 stimuli usually follow a “flashing” procedure of 2-dimension letters or images. Although using a small population, the preliminary results were classified in single trial with a standard statistical classifier and showed encouraging results. Further research will focus on the improvement of the visual paradigms and the exploration of new signal processing and classification methods.

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Robotic rehabilitation tool supporting up and down motions in the bathroom – analyses of the catapult-assisted taking-off mechanism

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ABSTRACT

Flexibility and quickness of biological muscles are of interest to people developing welfare robots and studying physiotherapy procedures. We focus on the transition process from sitting to standing in human motions, which needs to generate an instantaneous force at the moment of standing, and propose a robotic device to help the up-and-down motion in the bathroom by assisting the force when the backside is taking off from the lavatory basin. Our lightweight construction device allows disabled persons to move easily from the living space to the bathroom and assist its motion from the viewpoint of rehabilitation. In the prototype experiment, the artificial muscle—based on elastic-plastic materials by using rebound characteristics in an S-shaped structure—demonstrated that a cyclic motion triggers a generation of instantaneous force large enough to launch a ball. This suggests that the combination of the movable frame with the human body and the artificial muscle mechanism provide a user-friendly tool for self-supporting life of disabled persons.

1. INTRODUCTION

Robotic technology has been widely utilized in factory automations. However, the biological body and its control mechanisms display a flexibility and quickness with less power that far exceeds solid robots. Roboticists study mechanisms of bodily control and develop biologically-inspired systems using hydraulic actuators and electric motors instead of biological muscles. In the field of medical technology, improvements in raw materials show promise for the application of surgical prostheses and artificial limbs. Paralympic athletes with trans-tibial artificial limbs based on carbon fiber are good examples that show the advancement of plastics technology, which is expected to improve the physical fitness of disabled persons and bring down the cost.

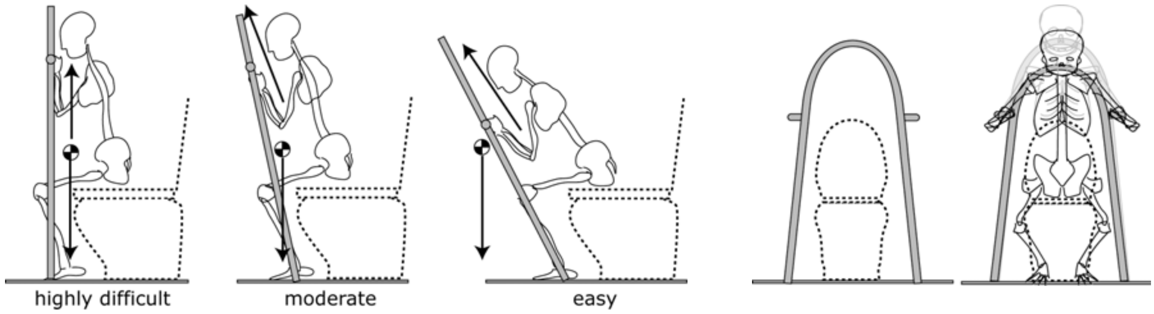
Elastic-plastic materials, also called bioorganic materials, are raising expectations for a new type of actuators [Smela, 2003]. But nonetheless there are problems with instabilities or nonlinear properties in motion control, and it is still difficult to design a single actuator device that certifies accuracy and repeatability at the same level as conventional electric motors. Indeed, biological muscles are flexible, which requires controlling softly and effectively, and the nervous system can learn how they work and control them by focusing the best timing and the direction of the force through neuronal impulses. Therefore, such new actuators made of bioorganic materials are expected to satisfy those necessary conditions. To produce an actuator from an elastic material, we have to specify 1) types of needed power, 2) structures to obtain the power and 3) control mechanisms to generate it quickly and repeatedly. In the present study, we focus on the quickness of actuator motions for jumping, which is one of the most difficult abilities for robots using electric motors, and investigated the rebound characteristics of a thin sheet of plastic material in an S-shaped structure. Thin steel plates are used for blade springs embedded in the bottom of the cart to absorb shock from the ground. An interesting mechanism is an instantaneous releasing process of accumulated stress, similar to the mechanism thought to cause earthquakes, and it can be applied to a jumping actuator in order to

support the human standing motion.

By using the nonlinear stress-strain relationship of elastic-plastic materials, we designed a prototype of the experimental setup to test the performance of the S-shape jumping actuator made of thin plastic, and investigated 1) conditions of shapes to generate an instantaneous force from power accumulation and 2) the degree of the instantaneous force. This fundamental experiment is crucial for exploring the possibility of prospective elastic-plastic materials for developing artificial muscles of disabled persons in the near future.

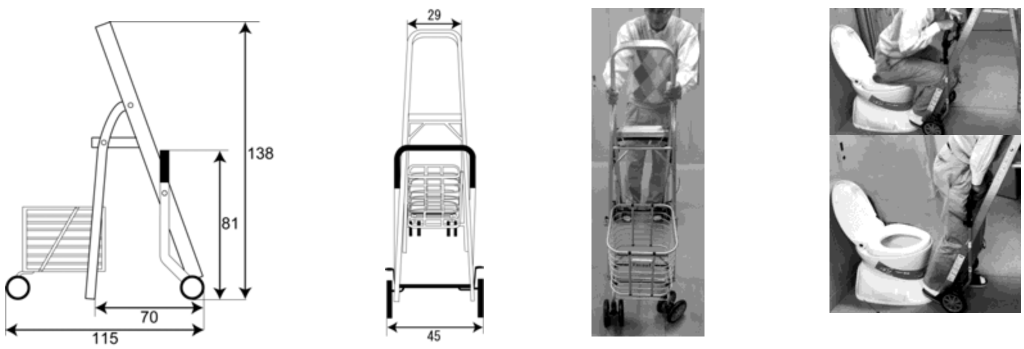
2. FRAME DESIGN FOR THE CATAPULT-ASSISTED MECHANISM

Firstly, we designed a framework of carriers for persons who are physically weak to assist the action of standing up and walking. Various circular walkers that help a stable standing walk are widely proposed and commercially provided. However, in the present purpose, the device needed the following properties: 1) treatment of the transition process between sitting and standing and 2) the compact size to fit it all even in the typically small Japanese lavatory (Fig. 1). In the first point, an inverse U-shaped frame inspired us to build the supporting frame to prevent falling down in a transverse direction (Fig. 1b) and to enable the user to focus on their body movement in only an anteroposterior direction (Fig. 1a). In the second point, compactness was designed as the frame's ability to fold its stems for changing modes between standing and walking, which was inspired by collapsible ladders (Fig. 2), and it can be conveniently carried into the small lavatory and opened again inside the room. We call this the catapult-assisted taking-off mechanism. The last problem was identifying the best mechanism for assisting standing force for disabled persons. Since there are various types of deficits, it is difficult for a single device to help all types of disabilities. In the present study, we focus on persons with cerebral palsy syndrome, in convalescence stage from a musculoskeletal injury, and damage in the motor control regions of the brain, because those patients are targets of rehabilitation in physiotherapy.



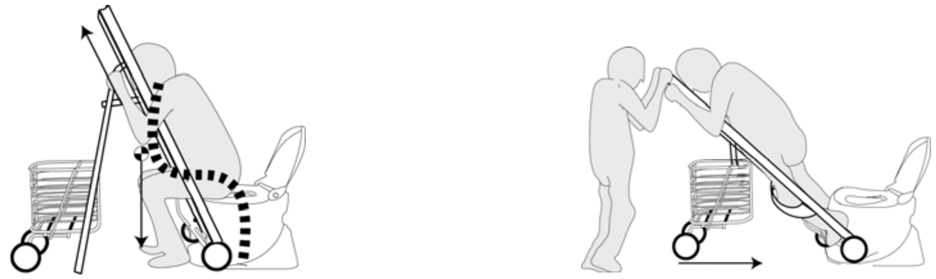
(a) (b)

Figure 1. *A musculoskeletal mechanism of the standing motion in the lavatory and our frame design. (a) Side view of the motion in three gradient differences of the inverse U-shaped frame. The circle and arrow denote the center of gravity and the direction of gravitational force. The other arrow indicates a countervailing power for standing. (b) The front view.*



(a) (b)

Figure 2. *The framework design of the carrier assisting with standing up and walking motions for persons who are physically weak. (a) Specifications and requirements for the device. We were inspired by collapsible ladders and designed a structure with an A-shaped side view. This structure is compact and the stems can be folded up into an A-shape and conveniently carried into the bathroom and opened again in the room.*



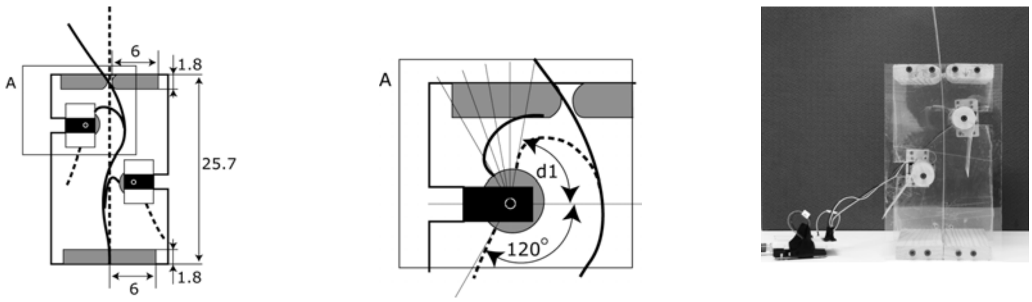
(a) *(b)*

Figure 3. *Applications of the proposed device. (a) The necessary power assist when the user is getting off from the lavatory basin. A S-shaped spring (dotted line) assists the user's force at the moment. (b) Another usage of the device to bring the patient from the bed to the lavatory. The basket in front can be used for the container of medical apparatus that is necessary for the patient, like an oxygen breathing apparatus.*

According to the restriction of freedom of movements, the device allows the user to concentrate the force direction and learn the best timing to generate an instantaneous force for standing (Fig. 3). In the previous studies, the S-shaped structure of elastic materials has been investigated [Tsuda et al., 2009; Sone and Wagatsuma, 2011]; here it is extended for standing motion.

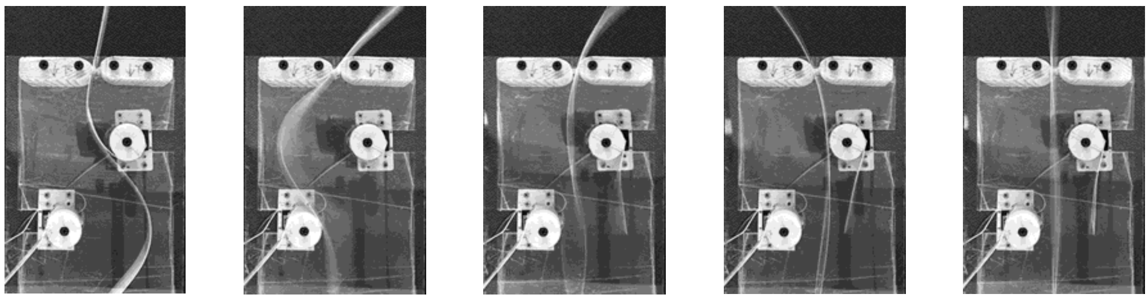
3. PROTOTYPE EXPERIMENTS

We designed a prototype of the S-shaped spring (Fig. 3a), as an artificial muscle based on elastic-plastic materials, by using a thin plastic plate. In the prototype experiment, the artificial demonstrated that a cyclic motion triggers a generation of instantaneous force large enough to launch a ball. The S-shaped thin plastic sheet is locked inside the box and flicked by synchronized cyclic motions of two serve motors (RS304MD, Futaba Corp.), which is controlled by the Arduino microprocessor board (Fig. 4). This experimental apparatus is able to modify the degree of the rotation at the setup point (Fig. 4a; right), and form a S-shape of the internal plate. Interestingly, the two blades with the motors make the plate form a S-shape and then release the accumulated power at the short moment for 0.24s (Fig. 5).



(a) *(b)*

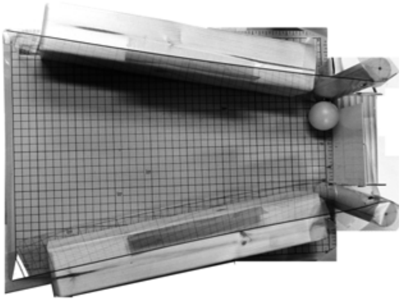
Figure 4. *The experimental apparatus of the prototype of the S-shaped spring as an artificial muscle based on elastic-plastic materials. (a) Specifications and requirements for the device [cm]. (b) The prototype of the device with two servo motors and the Arduino microprocessor board.*

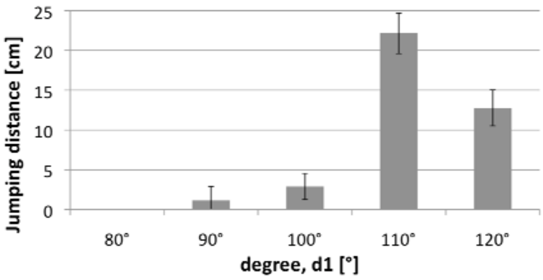


0.00s 0.06s 0.12s 0.18s 0.24s

Figure 5. *Snapshots of impact moments for 0.24s in the prototype experiment.*

In the experiment, a typical ping-pong ball (4cm, 2.7g) is used for verifying an instantaneous force in the S-shaped spring by measuring the distance the ball flies from the machine. We tested the effect of the degree of rotation at the setup point (Fig. 4a; right), varying from [80, 90, 100, 110, 120] [°]. The apparatus is set at the bottom of the experimental field with a certain gradient and the ball is set on the lower pocket (Fig. 6a) and the controller generates synchronized cyclic motions so that the plate forms an S-shape repeatedly. The power of the instantaneous force is measured by the jumping distance of the ball, *i.e.* the highest point of the jump. For each condition, we examined 100 flights of the ball. Excepting the 80[°] condition, the ball was successfully launched (Fig. 6b), generating the instantaneous force. The difference of the setup degree, d1, determines the relationship between initial positions of two blades (Fig. 5). This controls the timing of releasing of the upper blade after the movement of the lower blade, forming the best S-shape.





(a) *(b)*

Figure 6. *The experimental result to test the performance of launching the ball in the proposed mechanism. (a) Experimental setup. (b) Averaged jumping distance of the ball in the experiment with 100 trials in each condition, d1 as* [80, 90, 100, 110, 120] [°].

4. CONCLUSIONS

We focused on the generation of an instantaneous force in a human standing motion and proposed a robotic device to help the up-and-down motion in the lavatory. Our lightweight movable frame satisfied two requirements, which are assistance with the transition process between sitting and standing, and a compact size for carrying it in a Japanese lavatory. For the assistance of the standing motion, we investigated the performance a prototype of the S-shaped spring in the experimental apparatus and observed a successful generation of an instantaneous force by using thin plastic plates. This fundamental experiment was successfully demonstrated but further analyses are necessary to develop the mechanism for the human-sized S-shape spring, which should be adjustable for varying size and weight of the performer. The last problem is how an instantaneous force controls to fit movements of individuals with neurological disorders. In the viewpoint of rehabilitations, our current targets are individuals with problems in control and the device will provide a supportive power and inform the best timing and direction of the subject’s force, while the current device is difficult to apply to individuals with problems in muscle weakness because the S-shaped spring does not guarantee to supply an enough power for standing without their muscular actions. This result suggests that the combination of the movable frame with the human body and the artificial muscle mechanism provides a user-friendly tool for self-training and self-supporting life of disabled persons.

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Personalised stroke rehabilitation intervention using open source 3D software and the Wii Remote Plus

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ABSTRACT

The research presented in this paper proposes a novel low-cost customised Virtual Reality (VR) based, stroke rehabilitation system for the delivery of motivating rehabilitation sessions and evaluation of performance. The described system is designed to capture and monitor human upper limb motion using a low cost and commercially available accelerometer and gyroscope device, the Nintendo Wii remote and open source 3D software. This is the first project to successfully fuse the Nintendo Wii remote acceleration and gyroscope data to offer a real-time one-to-one representation of the controller in a VR environment. A pilot study established a high degree of user acceptability and high levels enjoyment using the tailor made games and personalised exercises in a chronic stroke survivor. Moreover, positive changes were demonstrated in all four outcome measures employed; of particular note were improved wrist control and greater functional use of the hand.

1. INTRODUCTION

Stroke is the largest single cause of long term disability in the United Kingdom (UK). It is estimated that 110,000 new strokes occur each year leading to an annual economic burden of more than £2.8billion (Department of Health, 2010). Upper limb problems are particularly common post stroke with 70% of stroke survivors experiencing significant problems. Treatment interventions most effective at improving upper limb movement are by nature intense, highly repetitive and functional. Boredom with such exercises prevails and adherence is problematic (Tijou et al, 2010); with 60-80% of people failing to comply with their prescribed exercise programme (Van Dulmen et al, 2008). This is exacerbated in the community where there are fewer therapists to monitor exercises and people describe feeling unsupported. It can therefore be seen that interventions with the ability to achieve the intensity and repetition levels to promote/drive upper limb recovery which can be monitored and adjusted remotely by specialists could potentially be highly clinically useful.

ReWiiRE (Research for Wii Rehabilitation) was an 18-month NHS (National Health Service) funded project (www.rewiire.org.uk). The project aim was twofold. Firstly to explore the current use of the Nintendo Wii console technology in physical rehabilitation programmes. Secondly to develop a personalised Nintendo Wii stroke rehabilitation intervention together with tailor-made games and therapeutic, functional upper limb exercises in partnership with stroke survivors.

2. RELATED WORK

Attempts have been made to use commercial accelerometer devices, such as the Nintendo Wii remote (also known as the "Wiimote") for rehabilitation purposes. The vast majority of studies have taken place in therapy clinics testing the use of the Nintendo Wii console and the Wii sports game with a limited number of stroke patients (Yong Joo et al, 2010; Saposnik et al, 2010; Williams et al, 2010). These studies along with ours showed that patients found the Wii intervention enjoyable and motivating but described limitations of use, particularly in terms of the duration of the exercises, the speed, a lack of registering the full range of movements (i.e. small movements made by stroke survivors) and the inability to hold the Wii remote.

Several studies have developed customised Wii-based interventions. These studies aimed at developing a VR-based system that captures the patient upper limb motion in a more accurate way compared to the

conventional Wii remote. These can be categorised into three main distinct groups depending on the technical methodology employed for customising the Wii remote technology, namely acceleration data from the Wiimote only (Shih et al, 2008; Leder et al, 2008; Palmke et al 2009; Matamoros et al, 2010; Alankus et al, 2011), the Wiimote as an IR (Infra Red) camera with the aid of LEDs (light-emitting diodes) (Attygalle et al, 2008; Jovanov et al, 2008; Scherfgen et al, 2009; Decker et al, 2009) and a hybrid of the two (Wilson et al, 2007; Martin-Moreno et al, 2008).

The first aforementioned group of customised Wii interventions employ one or two Wiimotes with a reverse engineered Application Programming Interface (API) to capture the patient motion by reading the Wiimote accelerometer data. Since these approaches obtain the position of the Wiimote in space using the acceleration data (that is the change in the linear acceleration as the patient moves the Wii remote in space) they suffer from a DoF (Degree of Freedom) limitation. More precisely these solutions offer accuracy only in 2-DoF as the acceleration data can only determine the pitch and roll movement.

The second group of customised Wii interventions employ a pair of Wiimotes, which are used as IR cameras detecting motion through the Wii's sensor bar or some custom LEDs, to build a low-cost motion capture system. The LEDs are usually attached to the patient (by means of a strap, thereby negating the problem of stroke survivor's ability to hold and operate the Wiimote) and as the exercises are executed, the range of motion is captured and mapped onto the system display. The limitation in this approach is that each Wiimote can detect up to four LEDs in space, thus restricting the range of movement and set of exercises that the patient can perform. Also care must be placed on the view angle of the Wiimotes' IR camera in order to reduce occlusion of LEDs as they patient moves his/her upper limb.

To the best of our knowledge the work presented in this paper is the first to propose the fusion of the Nintendo Wii remote acceleration and gyroscope data for the provision of a real-time personalised stroke rehabilitation intervention.

3. PROPOSED INTERVENTION

The developed system as depicted in Figure 1 comprises of three bottom-to-top layers, namely data collection, data fusion and motion tracking algorithm, and the 3D visualisation. The data access operation mainly includes functions that allow the application to acquire sensor data sent from multiple Wii remote plus to a personal computer via Bluetooth communication (in our study two Wiimotes were used per participant but more can be added). In the middle layer, the received information from the Wii remote sensors undergo a process of smoothing and multiplexing using a data fusion algorithm in order to achieve higher accuracy and precision. The end results are mapped into quaternion forms that translate the orientation of a constructed 3D body model and also form the data structure for the top layer. The top layer embraces the dynamic physical simulation of a 3D avatar animation in real-time. For the purpose of the animation, we employ Blender which is an open source 3D application.

The angular rate measurements captured by the gyroscope sensor can be used to distinguish true linear motion from the accelerometer readings. The gyroscope is not free from noise, but since the measured rotation is less sensitive to linear mechanical movements and without amplifying hand jitter, both of which accelerometers suffers from, it allows capturing more complex orientation with a relatively better estimate than we would obtain by using accelerometers alone. A sensible approach for maximising efficiency is to average or concatenate the data that comes from the accelerometer and gyroscope by using a data fusion algorithm and simultaneously, we have been able to employ a smoothing algorithm to remove any excessive noise from the signals while still retaining the useful information.

Filtering out and removing as much random noise as possible from the sensors' output raw information whilst retaining quality data is of fundamental importance. There are various methods for achieving this. Some of them involve very complex computations and offer impressive results whereas others use simple computational methods but lead to initial data being distorted. The choice of selecting the right trade-off depends on the characteristics of the signal (peak position, height, width, area, etc.) and system requirements. For smoothing the fluctuating acceleration values, we utilise a moving average function and for the angular velocity data from the gyroscope, a five-point window Savitzky-Golay (1964) smoothing filter is used.

The Wiimote sensors are very responsive, but they cannot respond to the linear movement accelerometers specialise in. Yet, as described in the above section, when a gyroscope and an accelerometer are combined, the pairing of sensors facilitates a highly accurate one-to-one representation of the control device in 3D space.

The rationale for the use of an Open Source 3D authoring tool is twofold. On one hand, it provides instant visual feedback of the patient movement that both the patient and therapist can view, store, evaluate and monitor. On the other hand, it creates opportunities for the development of high quality 3D graphical exercises, games and virtual environments that can act as an additional motivational tool. For an exercise treatment to be successful it must be engaging and participative as compliance with on-going physical activity and home exercise programmes are often poor and require behavioural change.

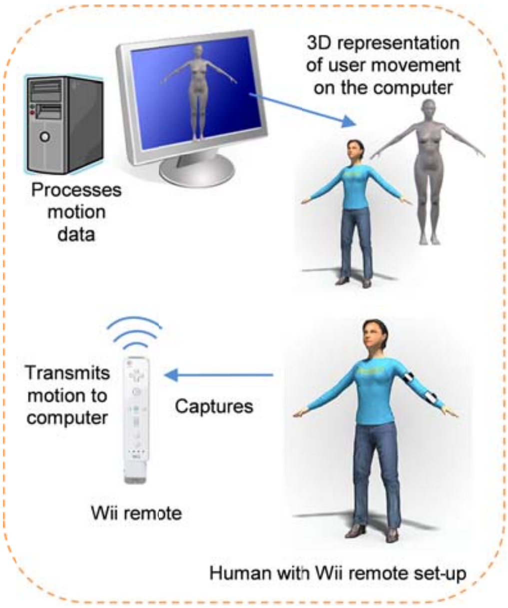

Figure 1. *Customised Wii Intervention System Architecture.*

4. PRELIMINARY RESULTS

The system was incrementally developed and tested by stroke survivors participating in the project. In addition, a single-case, feasibility before and after study was undertaken to field test the system, with a 32 year-old, right- handed, female, who had suffered a right sided stroke 12 years previously resulting in a left sided hemiplegia. The personalised treatment intervention was undertaken three times a week over a two week period with individual sessions lasting between 30-45 minutes inclusive of rest periods. Clinical change was evaluated using standardised outcome measures: the MAS (Modified Ashworth Scale), MAL (Motor Activity Log, Amount of Use subscale), FMA upper limb section (Fugl-Meyer Assessment) and NHPT (Nine Hole Peg Test).

Despite the short duration of the study, significant improvements were demonstrated particularly in the NHPT and MAL and concomitant self-reported functional improvements in everyday activities were noted. The stroke survivor described the activities practised through the personalised Wii system as fun and motivating. The ability to customise the exercises for example being able to alter the the speed and level of difficulty of the games kept her motivated as her capability improved.

5. CONCLUSIONS

This paper has presented the development of an innovative system which offers a customised stroke VR-based rehabilitation intervention by using low-cost and off-the-shelf game sensors, i.e. the Nintendo Wii remote combined with open source 3D software. This is the first project that fuses the Nintendo Wii remote acceleration and gyroscope data together to track the controller movements. The proposed system provides accurate and real-time one-to-one representation of the control device in VR space.

We are encouraged by the preliminary results and plan to extend the study in terms of both duration and sample size. Furthermore we wish to test the feasibility and acceptability of using the novel intervention for delivering stroke telerehabilitation for community dwelling stroke survivors.

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Relationship between sensory processing profiles and sense of presence

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ABSTRACT

'*Sensory Processing*' is the distinction, modulation and response to sensory input, and combines high or low neurological thresholds and high or low behavioral responses. We examined the impact of sensory processing on sense of presence in a flight VRE. Subjects (85) completed the Adult Sensory Profile, experienced a 10 minute VRE and completed presence questionnaires. According to expectations, Sensory Sensitivity correlated positively with presence for Minority (Arab) participants and those who failed to look at the window, and Sensory Avoidance correlated positively with presence. Contrary to expectations Sensory Sensitivity correlated negatively with presence for Majority (Jewish) participants and Sensory Avoidance correlated negatively with presence for Minority (Arab) participants. We conclude that for high Sensory Sensitivity individuals it is essential to ensure that distracting technological and environmental stimuli are kept to a minimum; for High Sensory Avoidant individuals, control of the environment is important; for those high on Sensory Seeking, interactivity in the VRE is important to enhance presence.

1. INTRODUCTION

Exposure, where the person is exposed in a controlled fashion to stimuli that arouse anxiety, is an essential component of treatment for phobias (Price 2006). Virtual Reality (VR) has many advantages over in vivo or in vitro exposure (Wallach, Safir & Bar Zvi, 2009), however it must be experienced as if it is real to generate "presence"(Lee, 2004). There is great interest in understanding the factors that are involved in producing presence (Wiederhold and Wiederhold, 2000). Although individual differences may be important variables (Safir and Wallach, 2011; Wallach, Safir, Samana, Almog, & Horef, 2011), studies have focused on technical factors rather than on personality components (Laarni, Ravaja, Kallinen, & Saari, 2005), and on sensory aspects of the environment, rather than at the way the individual processes these sensations, i.e. sensory processing. We suggest examining sensory processing, as a variable that may influence presence.

People differ in the way they experience and process sensory events (Dunn, 2001). '*Sensory Processing*' is the distinction, modulation and response to sensory input (Dunn, 2001). Dunn (1997) developed a model of sensory processing that combines neurological thresholds (which may be high or low) and behavioral responses (which may be passive or active). Individuals with low neurological thresholds and active responsivity avoid sensory stimuli in order to reduce sensations (*Sensory Avoidance*). Individuals with high neurological thresholds and active responsivity seek stimuli, and attempt to increase intensity in order to increase sensations (*Sensory Seeking*). Individuals with low neurological thresholds and passive behavioral responses (*Sensory Sensitivity*) are more sensitive to and stimulated by sensations, while individuals with high neurological thresholds and passive behavioral responsivity (*Poor Registration*) respond slowly, or not at all, to sensory stimuli. Sensory processing modes lead to differences in experienced reality, as well as to differences in processing VR. Therefore, we hypothesized that sensory processing mode will correlate with level of presence experienced in the VR Environment (VRE), and will influence behavior in the VRE. We employed VRE for flight. We predicted that:

- High *Sensory Sensitivity* (low threshold, passive response) subjects would be more aware of the VRE and experience higher presence. They would also act passively in the VRE and look less at the "virtual" airplane window.

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- High *Sensory Avoidance* (low threshold, active response) subjects would attempt to actively avoid exposure to sensation. Our VRE did not enable active avoidance; therefore, they should experience high presence. Subjects should also actively avoid sensation by not looking at the window or closing their eyes.
- High *Poor Registration subjects* (high threshold, passive response), fail to notice and respond to sensations. They would experience low presence. They would also act passively in the VRE looking less at the "virtual" window.
- High *Sensory Seeking* subjects (high threshold, active response) actively seek sensations, and long for them. Unfortunately our VRE did not allow for such behavior, therefore we predicted that these subjects would experience low presence. They should also be more active in the VRE, thus looking more at the "virtual" window.

2. METHODS

Subjects (85) completed Adult Sensory Profile (Dunn, 1999), experienced a 10 minute VRE and completed presence questionnaires (Presence Questionnaire – PQ, Witmer & Singer, 1998; Igroup Presence Questionnaire – IPQ, Schubert, Friedmann, & Regenbrecht, 1999).

We used a flight VRE (Virtually Better) with a helmet (HMD, EmaginZ800). Subjects sat in an airplane chair which vibrated relative to the VRE, experienced takeoff, flying, and landing. Looking forward they saw the seat in front of them, and looking to the left they were able to "look out" of the virtual window and see the changing scenery. Prior to exposure, participants were instructed to look around VRE and not just ahead.

3. RESULTS

We used Manova, t-test (with Bonferroni correction) and Pearson correlations to examine our hypotheses. In previous research (Almog, Wallach & Safir, 2009; Wallach, Safir & Samana, 2010) we found that ethnicity influenced both activity and presence levels in the flight VRE. Therefore, we examined our results separately for majority (Jewish) and minority (Arab) subjects. In this study, Arab participants experienced higher presence levels on two subscales (Natural- PQ, Experienced Realism- IPQ) than Jewish participants, contrary to our previous studies.

The majority of subjects (81%) looked at the virtual window. In accordance with our previous studies, subjects who looked at the "virtual" window experienced higher presence (Experienced Realism- IPQ). In addition, Arab participants looked at the window less than Jewish participants. Contrary to our predictions, we failed to find correlations between sensory processing mode and tendency to look at the window.

We predicted that Sensory Sensitivity (low threshold, passive response) subjects would experience higher presence. We found this correlation for our Arab subjects (Involvement - IPQ) and for those who failed to look at the virtual window (Involvement – IPQ). However, for our Jewish subjects, as well as for those who looked at the virtual window, contrary to predictions, we found that higher sensory sensitivity correlated with lower presence (Interface Quality for Jews, Involvement Control, Natural, Interface quality on PQ for lookers.).

We predicted that Sensory Avoidant (low threshold, active response) subjects would experience high presence. Subjects with high Sensory Avoidance reported higher presence (Natural-PQ). In addition, Arab subjects, contrary to predictions, produced negative correlations between Sensory Avoiding and presence (Involvement control – PQ).

We predicted that Poor Registration (high threshold, passive response subjects would experience low presence. We failed to find significant correlations with presence.

We predicted that Sensory Seeking (high threshold, active response) subjects would experience low presence. Contrary to our hypothesis, a significant positive correlation between sensory seeking and presence was found for subjects who viewed the window.

4. CONCLUSIONS

Individuals with high Sensory Sensitivity are aware of and sensitive to sensory input. In the VRE they notice the weight of the HMD, exterior noises, etc. They are also sensitive to differences between the VRE and their previous experiences. This will result in experiencing the VRE as unreal, lowering their sense of presence. In

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addition, sense of control in the VRE is important for them, perhaps because they feel bombarded with stimuli and thus want to control the intake of new stimuli. In previous research (Samana et al., 2009) we found that internal locus of control leads to higher presence. Therefore, for Sensory Sensitivity participants, it is necessary to ensure that distracting technological and environmental elements are kept to a minimum, to allow them to gradually adjust to the VRE. This should enable them to experience greater presence. We have previously commented (Wallach, Safir, et al., 2011) that it is less important that the VRE be an exact duplicate of the real world, but it should not contain discordant elements which interfere with creation of mental representation of the environment. This is extremely important for individuals with high Sensory Sensitivity.

As predicted, participants with heightened Sensory Avoiding tendencies experienced higher sense of presence. However, we found, contrary to our hypothesis, that Arab participants produced a significant negative relationship between Sensory Avoidance and presence, particularly control aspects of presence. Therefore, it is important to adapt the VRE for minority participants so they may experience some control of the environment and not attempt to cognitively or mentally escape the VRE.

We failed to find a significant correlation between presence and Poor Registration. This may have occurred because the majority of our subjects had normative or reduced tendencies for Poor Registration.

Contrary to our hypothesis, a significant positive correlation between sensory seeking and presence was found for subjects who viewed the window. We propose that turning one's head to look at the window is an active response, enabling subjects high on Sensory Seeking to increase the intensity of their experience, to invest in sensory experiences, and be less preoccupied with distracting factors. Therefore, we conclude that for individuals with heightened sensory seeking modes, it is important to enable active interaction within the VRE.

The importance of the relationship between sensory processing and presence brings us one step further in our quest for the "ideal" VR user profile. It provides us with an additional a priori variable we may use to determine whether VR will be effective or not for a particular individual. It also enables us to understand how we may adapt the VRE for each individual in accord with his/her sensory profile.

To summarize, our results indicate that it is important to employ sophisticated technological interface**s** and to minimize distracting elements for subjects with high Sensory Sensitivity. Thus it is important to give them assignments which will enable them to focus on the virtual experience. We also suggest that it is important to design the VRE to prevent individuals with a high level of Sensory Avoidance from activating avoidant responses, and enable them to experience a degree of control in the environment. In addition, it is important to modify VRE's, to enable interactivity for individuals with high Sensory Seeking, for whom control is more important than technological sophistication.

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Haptics visualisation of scientific data for visually impaired users

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ABSTRACT

Visualisations of numerical data often used in science, engineering and mathematics are not easily accessible to visually impaired students. This paper describes the development and evaluation of a multimodal system to present graphical data in real-time to those students. Haptic interfaces form the primary interaction, along with auditory feedback allowing graphs to be perceived through touch, sounds and speech. The results show that the system can be used to quickly and accurately obtain information from a graph. It has been demonstrated that haptic devices can be successfully used to allow access to line graph data.

1. INTRODUCTION

Large amounts of numerical data can often have little meaning by themselves and therefore visualisation techniques, such as graphs and charts, are used to aid understanding. These techniques are frequently used to convey information, particularly within the disciplines of maths and science. Unfortunately, such visualisations are often not accessible to the visually impaired community (Doush & Pontelli, 2012), (Wall & Brewster, 2006), (Roberts et al., 2002). In order for visually impaired individuals to have greater access to education and careers in these fields it is important to develop techniques that allow non-visual perception of numerical data sets. It is hoped that this inclusion will allow individuals to have more financial security and a greater level of independence (Doush & Pontelli, 2012).

In order to access textual data most blind computer users will use screen readers, Braille cell displays, Braille embossing printers or a combination of these devices. There are fewer tools available to access visual representations of data. Some examples include feeling a raised-line graph created by a Braille embossing printer in graphics mode or using microcapsule paper. In addition, hand-made representations using paper and string can also be used. However, these methods tend to be either, ineffective and inefficient for data interpretation, or are slow and labour-intensive to create and static in nature, hence impossible to update in real-time (Fritz et al., 1996).

The aim of this project is to enable greater access to scientific data for visually impaired students through the development of multimodal tools that can present data in real-time, using a combination of haptic and auditory interfaces. This paper describes the development of a prototype system written in C++ which takes data input from files generated through Matlab and is able to produce output on various haptic devices. Matlab was chosen as it is widely used in science and engineering applications, although the technique may be applicable to other plotting software. Different modes of exploration of the graphs are considered, as well as additional functionality, such as zooming. The implementation of sonification techniques, including text to speech output is also discussed. Finally, the experimental procedures used to evaluate the system are detailed.

2. HAPTICS

The system was developed in C++, using the CHAI 3D open source haptics library. This was chosen as it is a light and easily extensible platform which offers the key advantage of supporting several haptic devices; including the Novint Falcon and Force Dimension Omega. The Falcon is a low cost device, where as the Omega is a more expensive and high fidelity device, designed for performance. The data for the graphs are created via Matlab and saved in a text file. This can then be immediately read by the system and used to create a graph made up of line segments. There are two modes in which the haptic graph can be explored (Roberts et al., 2002).

2.1 *Modes of exploration*

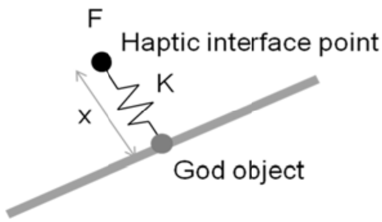
The first mode is the unconstrained mode, where the user is free to move across the surface on which the graph is represented. The line of the graph has a magnetic attraction effect which gets stronger as the user gets closer to the graph. This means that it feels like a bump on the flat surface, similar to the raised line of swell paper or a Braille embossed graphic.

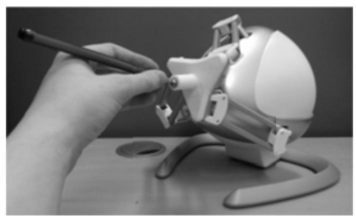
The second mode is the constrained mode, where the user's movement is restricted so that they can only easily move along the line of the graph. The line feels like a groove in a flat surface. This effect is achieved by projecting the HIP (Haptic Interface Point) onto the line to create a 'God Object' and simulating a contraction spring between this and the user. The God Object represents the desired position of the user and the spring creates a force which pulls the user back to this position, figure 1.

2.2 *Additional functionality*

Zooming functionality was implemented to allow the user to explore key features in more detail. The HIP is used as the focus for the zooming and this focus is moved to the centre of the workspace after zooming. This allows the user to explore around the area on which they have zoomed in. After applying several zoom commands the graph can end up in a position where not all of it is accessible. The user can reset the graph to the original size and position. This will also pull the user to the start of the graph so they immediately know where they are. Table 1 summarises the keyboard shortcuts.

In addition to the standard ball interface, a custom pen interface was also developed, figure 2. This allows the user to feel as if they were drawing the graph. The default orientation of the graph is vertical, as if it were on a wall. However, it can also be used in a horizontal orientation, which feels like writing on a flat table surface. These additional features allow the user to customise the system to suit their preferences.





e *'con*

3. SONIFICATION

As there is only one point of contact with the haptic device this limits the bandwidth of data that can be perceived by the user. One method of overcoming this limitation is to use a multimodal approach. For example, combining sonification techniques with the haptic interface (Roberts et al., 2002). Information can be encoded using sonification techniques by altering the timbre, pitch, volume and pan of notes (Doush & Pontelli, 2012), (Wall & Brewster, 2006). Sonification was implemented via a Midi extension to the BASS open source sound library. Furthermore, the Microsoft Speech API was used for text to speech output.

Table 1. *Keyboard shortcuts for system.*

Keys	*Actions*
u / c	*Unconstrained / constrained mode*
i / o	*Zoom in / zoom out*
h / v	*Horizontal / vertical orientation*
t	Read out coordinates of current point
r	Reset graph and snap to start
+ / -	Increase / decrease sonification volume
→ / ←	Increase / decrease speech rate
↑ / ↓	Increase / decrease voice volume

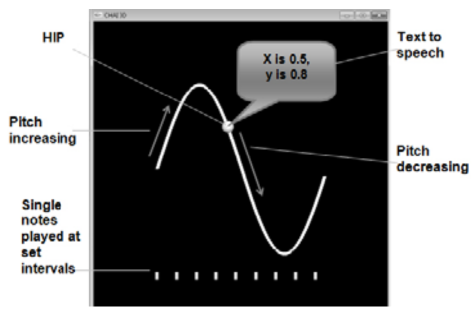


Figure 3. *Sonification of a graph.*

The y axis was sonified by linearly mapping the data value to the pitch of a note (Brown et al., 2003). As the y value increases so does the pitch and vice versa. Initially, a MIDI piano instrument was used and individual notes were played at the calculated pitch. This produced a very staccato output; therefore, the MIDI whistle timbre was used to produce a single sustained note. The pitch of this note was then altered with the y value by using the MIDI pitch bend event. This produced a much smoother, continuous sound. In addition to

helping to identify the shape of the graph, sonification techniques can also be used to provide context to the graph. Single MIDI notes were played at set intervals along the x axis of the graph. This provides the user with a sense of scale so that they can estimate how far along the graph they have moved.

The haptics and x and y sonification only provide the user with an overview of the graph. 'Text To Speech' functionality was implemented in order to enable the user to access the more detailed data. When the user presses a key the system reads out the current x and y coordinates if the user is on the graph. This functionality is customizable, so that the user can choose their preferred speech rate and volume. A visual representation is also given to assist a sighted person who may be interacting with the student.

4. MULTIPLE PLOTS

Some tasks require users to compare two graphs for example, determining the phase between two sinusoids. Previous research has shown that exploring two haptic lines on one device or a haptic and audio line can be confusing, particularly when the lines cross (McGookin & Brewster, 2006), so it was proposed to use two devices at once to explore two plots, one on each device. To achieve this, a second window was created with a second graph. Both graphs can be explored at once using two devices. In order to carry out particular tasks on a graph, such as zooming, the user needs to swap between the graphs so that the desired graph is in focus. The user can also feel the HIP of the other graph when the two HIPs are in the same place.

5. EXPERIMENTS

Initial evaluations of the system with visually impaired users were conducted during the development phase in order to ensure that the system met the users' requirements. The users were introduced to the system and the different functions available for exploring the graph. They tested different devices, interfaces and orientations and were asked for their feedback on all of these areas.

A between-subjects experiment was conducted, once the software had been completed, with one visually impaired user and seven sighted users whose visual field was restricted. Users were given an initial training session to become familiar with the system. This was conducted alternately between the Falcon and Omega devices in order to reduce bias in the experiment. Users were then asked to complete a series of tasks, each repeated for four graphs:

1. Identify the highest point of a graph using both devices separately.
2. Identify which of two graphs has the largest maximum value using two Falcons.
3. Estimate the proportion of a velocity-time graph for which the velocity is constant using a Falcon.

Finally, users were asked to complete a questionnaire.

6. RESULTS

The initial evaluations showed that the system can successfully enable a user with vision impairment to identify a graphical representation of a data set. A summary of the results from the experiment are given below (White, 2011). The questionnaire results showed that all of the users preferred the constrained mode and used this to complete all of the tasks in the experiment.

Table 2. *Average performance for finding max height.*

	Time (secs)	Accuracy (%)
Falcon	46 (± 33)	99 (±1)
Omega	40 (±24)	99 (±2)

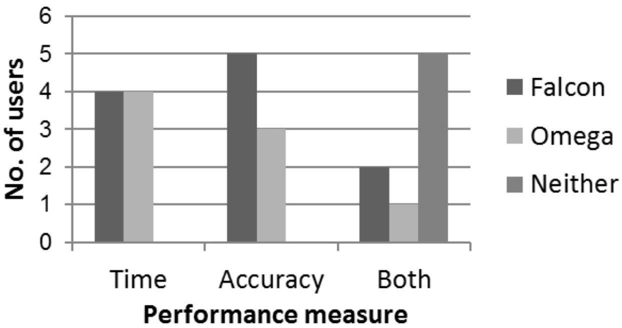


Figure 4. *Best device for different performance measures.*

The results, shown in table 2, demonstrate that both the Falcon and Omega enable the user to find the maximum height of a graph with 99% accuracy on average. This demonstrates that the system allows consistent and reliable performance. It also indicates that the high fidelity of the more expensive Omega is

not required in order to complete such tasks successfully. On average users completed the tasks 5 seconds quicker with the Omega. However, in comparison with the time taken to produce other aids, such as swell paper, this is insignificant. The results for the visually impaired participant were within one standard deviation of the average, suggesting that valuable conclusions can be drawn from experiments with sighted users. Furthermore, the questionnaire results agreed with the experimental results as on average users rated the two devices as equally easy to use.

Figure 5 shows that for approximately 90% of the sets of graphs users were able to correctly identify which had the largest maximum. This suggests that the multiple plots functionality successfully enables users to compare two graphs at once. This could be further improved by using the same scale for both plots in order that a direct comparison can be made more easily.

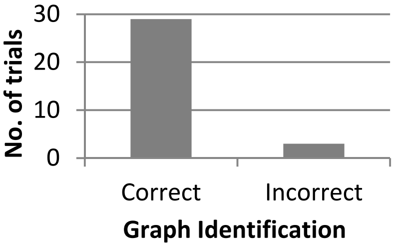


Figure 5. *Identification of graph with largest maximum.*

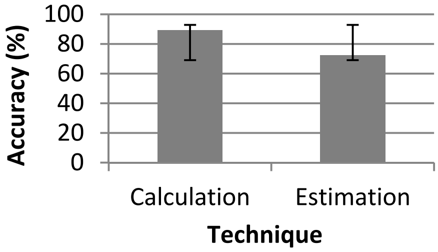


Figure 6. *Average accuracy of proportion found.*

When asked to find the proportion of a velocity-time graph for which there was a constant velocity, users chose one of two approaches. Some estimated the answer directly from the haptic feedback or x axis sonification, whilst others read out the values of the significant points and used these to calculate the answer. Figure 6 shows that on average users who calculated the answer tended to be more accurate. This suggests that the text to speech output is a vital part of the system. Furthermore, it indicates that if users were trained to use a specific approach they could achieve a higher level of accuracy overall.

7. CONCLUSIONS AND FUTURE WORK

The results clearly show that the system developed can be used to quickly and accurately answer questions about a graphical representation of a data set, using haptic and audio feedback. It has been demonstrated that both the Falcon and Omega devices can be successfully used with this system. Furthermore, the results suggest that with further training users could achieve even better performance. The system could be extended for use with other types of graphs, including 3D representations of data. It is planned to release the code as an open source project on Sourceforge.net in the near future.

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Augmented reality discovery and information system for people with memory loss

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ABSTRACT

Augmented Reality (AR) merges computer generated objects with real world concepts in order to provide additional information to enhance a person's perception of the real world. This paper describes the work undertaken for an MEng project to investigate the potential of using AR to assist people who have memory loss with simple everyday tasks such as making a hot drink or cooking basic meals. The aim of the Augmented Reality Discovery and Information System (TARDIS) is to help people live independently in their own homes for as long as possible and without relying as heavily on carer support.

1. INTRODUCTION

Augmented reality (AR) is a technology whereby a user's view or vision of the real world is enhanced or augmented with additional information generated from a computer model. The enhancement may take the form of labels, 3D rendered models, or shading modifications (Azuma, 1997; Azuma et al, 2001). Although defined in the early 1990s (Caudell and Mizell, 1992), exploitation of early research and development was hindered by a lack of processing capability. However, since 2007, largely driven by growth in the smartphone market, Augmented Reality has started to realise its potential (Papagiannakis et al, 2008). In addition to high resolution displays, smartphones and other mobile devices now have the necessary processing power to detect objects and events in the real world and to overlay additional information for the user. Software platforms such as Metaio (Metaio, 2012) and Layar (Layar, 2012), and AR development tools such as String™ (String, 2012) or Vuforia (Vuforia, 2012) also facilitate the development of AR applications for Apple, Android and Windows platforms. They can track position using Global Positioning Systems (GPS), and have a built in compass, markers and 2D textures making them very versatile. These features coupled with the ability to augment 3D models, images and audio means that applications exploiting this technology can be created with relative ease. Applications now exist, for example, to assist users in various tasks such as navigation, finding a restaurant's menu, interactive advertising and tracking assets in a war zone.

2. RATIONALE

Statistics show that 10% of all people above 70 suffer from memory loss [Health Care Information.org, 2012] and this is rapidly increasing. There are a number of different causes for memory loss, with ageing being the predominant one. Diseases such as Alzheimer's which is a form of dementia mostly affect older people and account for over 50% of all memory loss, although other causes include head injury and seizures.

A number of projects have utilised technology to help people with memory loss undertake everyday tasks and/or live more independently including the COACH prompting system which uses audio and audio-visual cues to autonomously guide participants through a hand washing task (Mihailidis et al, 2008) and Bonanni's proposals for a kitchen equipped with sensors, projectors and touch screens (Bonanni et al, 2005). Other smart home adaptations remind people to turn off taps, turn off the cooker, go back to bed, or alert carers (Dementia Voice, 2012)]. iWander is an Android application that uses GPS and standard communication capabilities to remotely monitor people with dementia who are prone to wandering through the use of audible warnings or directions about their whereabouts (Sposaro, 2010]. PiTaSu uses a camera, wrist-worn accelerometer and a projector worn by the person to overlay additional information about tasks being undertaken onto any surface the user is pointing towards (Goshiro et al 2012).

In this paper we investigate the use of AR for assisting people, who have suffered memory loss, through a stroke, dementia, or head injury, with simple everyday tasks. Examples of such tasks include making a hot drink or cooking basic meals. The aim of The Augmented Reality Discovery and Information System (TARDIS) is to use low cost technology that does not require any special adaptation of a users environment to assist them with everyday tasks around the home and with later expansion to include other scenarios, for example whilst out shopping. The goal is to help people stay in their own homes safer and for longer without relying so heavily on carers.

3. AUGMENTED REALITY DISCOVERY AND INFORMATION SYSTEM

Memory loss means that people sometimes find it hard to carry out certain simple tasks that are essential for basic living. A person using TARDIS has a tablet device (chosen as its screen is easier to see than a smartphone screen) which runs the AR software, and attached to which is a high quality webcam which they wear around their neck as a pendant. This captures their real world view and relays it to the tablet device which is in a durable case that is easy to carry around as shown in Figure 1.

Figure 1. *Mock-up of user interacting with TADIS system.*

TARDIS consists of tracking software, which provides interaction with the real world and allows graphics to be overlaid on a screen and displayed to the user. The software is based on a C++ library, SudaRA, which builds on the ARToolKit library (Univesrity of Washington, 2012). It allows fiducial markers (black squares with patterns inside that can be linked to one or more 3-D objects) to be detected and it also adds the capability to insert 3D models, interface buttons and audio into the application. Figure 2 shows the flow of the software.

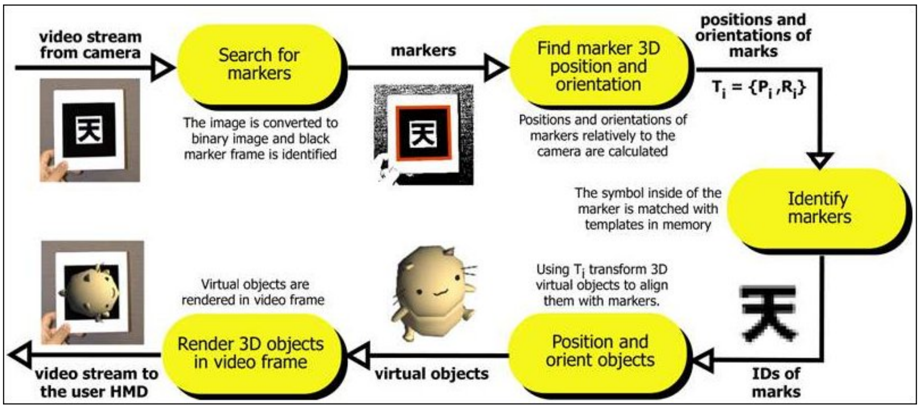

Figure 2. *AR stages for display and overlaying of information [University of Washington].*

An augmented world could become a hectic one if the user is presented with too much information. Therefore, to reduce the overload of information and to make the user interface simple as possible the system has situational awareness and uses contextual menus. For example when the webcam is pointed at the kettle a menu appears with a list of relevant drinks to be made. This can be tailored to the individual when the system is set up in the person's home, so that if they only like to drink tea and hot chocolate then just these two options will be displayed. The system then takes the user through each step of how to make their selected choice.

There are a number of types of information which can be displayed over the real world including 3D models, images, text and sound. Choosing the correct combination of these is very important or it could lead to confusion for the user. The images and models can be customized for each user so that when the kettle is displayed it looks similar to their own, or the default can be used. Audio is used to support the visuals on

screen, for example, when the kettle is detected the menu is described by a short piece of audio. This re-enforces the visual aids, but can be turned off if it is not required.

Each task is split into a number of stages, as each stage is completed it steps to the next stage, thereby ensuring a methodical way of carrying out the task so that the user does not get confused. Each stage has different overlays and animations attached to it to describe what needs to be done.

4. USING TARDIS

4.1 Use Case

Consider, John, a 73 year old male who lives at home with his wife Joan. They both have various health issues, John's includes a mild case of Dementia; he can cope for the majority of the time in performing everyday tasks around the home, however sometimes he can't think of what to do to achieve some simple tasks. For example, some days he can identify the cooker, but can't remember how to cook a meal or can't remember how to set the washing going. In Figure 3 a shortened storyboard for the purpose of this paper can be seen which shows the steps TARDIS displays to assist John to cook beans.

1. Get out a saucepan and a can of beans
2. Open can using a can opener
3. Pour beans into saucepan and heat on a medium heat for 3 minutes
4. Turn off hob, pour beans onto a plate.

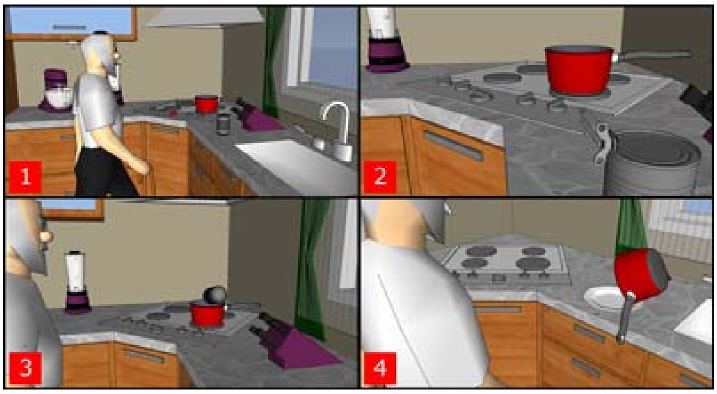

Figure 3. *Partial storyboard associated with cooking beans.*

4.2 Results

The TARDIS system can successfully load in 3D models and pair them with real world markers. These markers can be attached to the objects to be tracked as shown in Figure 4 which demonstrates a shortened use case of making a cup of tea. When the kettle is detected the contextual menu for making a drink is automatically displayed (4b). If the cooker or other programmed device was detected then a different menu would be shown. The user can then select from a list of drinks (4b). When one is selected the system searches for all the necessary items, in this example the kettle, a mug and a tea bag (4c). Once these have been detected it prompts the user to fill the kettle, giving precise instructions (4d). It then progresses through each stage required to make a cup of tea. The audio prompts can be recorded specifically by a carer to remind the person where each item is kept and also in a voice that is familiar to them.

5. CONCLUSIONS

Currently TARDIS is in early prototype stages with proof-of-concept having been successfully demonstrated. The next stage is for the concept to be developed into a more robust system with improved user friendliness before being tested by users with a range of conditions related to memory loss and apraxia. Development at this next stage will be undertaken using more sophisticated AR toolkits such as String™ (String, 2012) or Vuforia (Vuforia, 2012), in combination with a 3-D engine such as Unity (Unity, 2012) in order to improve rendering of the objects and interactivity within the scenarios. Marker-less tracking, textures on the 3-D models and functionality for carers to create and individualise scenarios have been identified as useful features for inclusion.

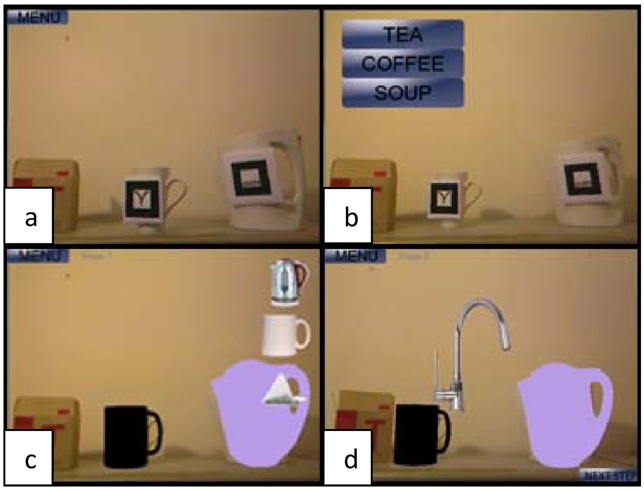

Figure 4. *Screenshots from developed system – making tea.*

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