Proceedings of the 10th international conference on disability, virtual reality and associated technologies (ICDVRAT 2014)

The 10th International Conference on

Disability, Virtual Reality and Associated Technologies

Proceedings

Edited by:

Paul Sharkey
Lena Pareto
Jurgen Broeren
Martin Rydmark

2 to 4 September, 2014

Gothenburg, Sweden

AN INTERNATIONAL SOCIETY FOR VIRTUAL REHABILITATION CONFERENCE

ICDVRAT 2014

The papers appearing in this book comprise the proceedings of the 10th International Conference on Disability, Virtual Reality and Associated Technologies, held between the 2nd and 4th of September, 2014 in the Gothenburg, Sweden. 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.

Please use the following format to cite material from these Proceedings:

> Author AB, Author, CD, and Author, DE (2014), Title of paper, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. *n–m*, Gothenburg, Sweden, 2–4 Sept. 2014.

Proceedings reference number: ISBN 978-0-7049-1546-6

Published by

The University of Reading

For information, contact: ICDVRAT, School of Systems Engineering,
University of Reading, Whiteknights,
Reading, RG6 6AY, UK

Phone: +44 (0) 118 378 6704 Fax: +44 (0) 118 378 8220

Email: *p.m.sharkey@reading.ac.uk* Web: *www.icdvrat.org*

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Printed in the UK.

Conference Schedule at a Glance

Tuesday, 2 September, 2014

08:00	Registration/Information Desk opens from 08:00
08:40	Welcome
09:00 – 10:00	Session I: Elderly Studies/Dementia
10:00	Coffee
10:30 – 11:30	Keynote I: Martin Rydmark *on* Neurological Care & Rehabilitation
11:30 – 12:30	Session II: Stroke Rehabilitation
12:30	Lunch
14:00 – 15:20	Session III: Behavioural and Psychological Disorders
15:20	Coffee
15:50 – 16:50	Session IV: Upper Limb Rehabilitation I
17:30	Reception

Wednesday, 3 September, 2014

08:00	Registration/Information Desk
08:40 – 10:00	Session V: Body Movement Training
10:00	Coffee
10:30 – 11:30	Keynote II: Nils-Krister Persson *on* Smart Textiles
11:30 – 12:30	Session VI: Evaluating Technologies
12:30	Lunch
14:00 – 14:40	Short Paper Podium Presentations
14:40 – 16:50	Poster Presentations *&* Interactive Demo Session
15:20	Coffee
c. 18:30	Boat Departs for Älvsborg Fortress, Gotheburg Archipelago Conference Dinner

Thursday, 4 September, 2014

08:00	Registration/Information Desk opens from 08:00
09:00 – 10:00	Session VII: Upper Limb Rehabilitation II
10:00	Coffee
10:30 – 11:30	Session VIII: Cognitive Training
11:30 – 12:30	Session IX: Real/Virtual Comparative Studies
12:30	Lunch
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15:50	[*Conference Closed*]

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Session X Haptics & Speech Training

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Internet address references within the papers presented in this volume were accessed and checked to be valid during the week 8–15 July 2014.

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Conference Series Archive

Paul Sharkey, University of Reading, UK

Introduction

The purpose of the 10th International Conference on Disability, Virtual Reality and Associated Technologies (ICDVRAT 2014) 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 18th 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), Viña del Mar/Valparaíso, Chile (2010) and LAval, France in 2012.

After peer review process, the International Programme Committee selected 33 Full Papers for presentation at the conference, collected into 10 plenary sessions: Elderly Studies/Dementia, Stroke Rehabilitation, Behavioural and Psychological Disorders, Upper Limb Rehabilitation I & II, Haptics & Speech Training, Evaluating Technologies, Cognitive Training, Real/Virtual Comparative Studies and Body Movement Training. There will be an additional 32 Short Papers presented at a Poster Session. The conference will be held over three days between the 2nd and 4th September at the Wallenberg Conference Centre of the University of Gothenburg, Sweden.

For the 2014 conference, there will be two keynote addresses, the first from Martin Rydmark of Gothenburg University, addressing the issues of remote communication, examination and training in neurological care and rehabilitation, and the second from Nils-Krister Persson of the University of Borås, on the topic of smart textiles as a future technology for the fields of disability and 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 2014, we welcome all delegates to the Conference and sincerely hope that delegates find the conference to be of great interest.

Jurgen Broeren, Lena Pareto, Martin Rydmark and Paul Sharkey

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The main sponsors of ICDVRAT 2014 are:

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and

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The Sahlgrenska Academy is the 2014 sponsor of the Keynote Speakers and the Conference Reception.

The organisers wish to express their gratitude to the other major sponsors of the conference:

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

Conference Prizes

The conference awards 4 prizes: Best Paper, Best Student Paper, Best Short Paper and Best Student Short Paper.

Bright Cloud International Corp (www.brightcloudint.com) is the 2014 sponsor for Best Full Paper and Best Short Paper awards.

The International Society for Virtual Rehabilitation (www.isvr.org) is the 2014 sponsor for Best Student Full Paper and Best Student Short Paper awards.

Student papers are papers where the primary author is affirmed to be the student and where the paper is presented by the student at the confereence. These papers are identified prior to the conference on submission of the final paper.

This is Gothenburg

Text from Gothenburg Tourism Agency

Gothenburg, Sweden's second largest city, is found on the west coast of Sweden, right in the heart of Scandinavia. The city has got plenty to offer – with lots of great shopping, a flourishing restaurant scene and the stunning archipelago just around the corner. The archipelago is easily reached by a 30-minute tram ride from the city centre.

Gothenburg was founded in 1621 by Gustav Adolf II and since then has undergone an exciting journey from being a shipping and industrial city to a creative hub for innovation. Today, the city boasts a number of internationally successful companies within marketing, architecture, web design and special effects for the film industry. Local fashion from Nudie, Velour and Monki is becomingly increasingly common in international magazines.

The atmosphere in the city is one of "easy going" genuineness. A strong café culture reveals itself in the tonnes of cafés that often serve their own roasted coffee. Fika is a Swedish word you soon will learn to love! "There is a greater sense of freedom in Gothenburg. It is more about being original than being cool." Ebbot Lundberg – Soundtracks of our lives.

Shopping, Music & Food

Gothenburg fashion is characterised by a relaxed but stylish tone. Explore a mix of department stores, malls, trendy design boutiques and charming independent shops. The Scandinavian design tradition is characterised by minimalism design and functionality. In Gothenburg you'll find everything from the latest trends in fashion by local and international designers, to unique vintage and interior design. What's more, they are all within walking distance from each other.

During the summer, Gothenburg hosts a number of international music festivals and concerts right the centre of town: Way out West (MTV award for the most innovative festival 2011 and on the top ten list of festivals in Europe by the Independent 2012), Metaltown and Summerburst, just to mention a few. Intimate club gigs and DJ performances can be found at the city's bars and nightclubs.

Gothenburg was appointed the Culinary Capital of Sweden 2012 and thus strengthened its reputation as a gastronomic hotspot in Northern Europe. Closeness to the sea results in top-quality, fresh fish and seafood and there is a strong tradition among local chefs to work with locally-produced and seasonal raw ingredients. In the Gothenburg archipelago it's all about fish and seafood – best enjoyed by the ocean. Is there any better place to enjoy dinner or lunch than at a restaurant overlooking the sea or a city canal? Judge for yourself at the Conference dinner!



The West Coast Archipelago

The archipelago of Gothenburg stretches along the coast like a string of pearls. You don't have to travel far from the city to find charming villages, stunning nature and beaches. Seal safaris, sea-fishing and boat excursions are just some of the activities available on the west coast.

The islands are one of Europe's most beautiful archipelagos. They comprise around 10,000 beautiful granite islets, rendered almost smooth during the ice age. Idyllic villages have sprung up all along the coastlines of these fascinating islands. If you're looking for peace and quiet, you can simply stop for a picnic, hire a kayak or a bicycle. Marstrand Island boasts Carlstens fortress and is also known for its party scene and international sailing events. And do not forget the Älvsborgs fortress, located on a small island in the Gothenburg archipelago, the location of the 2014 Conference dinner.

Bucket List ~ Gothenburg

1. FESKEKÔRKA. The "fish-church", a market hall for fish and shellfish in a characteristic building from 1874, with a church-like design.
2. HAGA. A charming neighbourhood with pedestrian-only streets, well-preserved wooden houses, small shops and nice cafés from 17th century.
3. THE MUSEUM OF ART. Nordic art featuring Carl Larsson, Edvard Munch, Anders Zorn and many others.
4. LISEBERG. Amusement park, with the new roller coaster Helix: 1.4 km long, 7 inversions, 3 airtime hills and plenty of drops, twists and turns.
5. MAGASINSKVARTERET. A trendy neighbourhood shopping area for everything from interior design to vintage fashion.
6. NEW ÄLVSBORG FORTRESS. The fortress in the harbour inlet is one of the most well-preserved in Sweden.
7. SKANSEN KRONAN. A fortification built 1687-89 which is nowadays a spectacular outlook in the middle of the charming Haga district.
8. THE GOTHENBURG ARCHIPELAGO. You will see a glimpse from the boat taking us to the conference dinner at the New Älvsborg fortress.
9. THE GARDEN SOCIETY. One of the most well-preserved 19th century gardens in Europe and a green oasis in the middle of the city.
10. UNIVERSEUM. The biggest science centre in Scandinavia. Here you can discover space, the rainforest, the ocean and much more.

Keynote: Martin Rydmark

Remote communication, examination and training in neurological care and rehabilitation

Martin Rydmark

The Sahlgrenska Academy, University of Gothenburg, SWEDEN

ABSTRACT

Organization and tools for home or remote ICT-based patient centered care for individuals with neurological disease or brain damage have been developed and tested on patients during the last 15 years by our research group; this will be briefly presented and further improvements are suggested. Neurologic disease and damage cause profound alterations to a person's life. The conditions are often life long and demand continuous treatment and rehabilitation, as well as support in the activities of daily life. Communication with health care as well as relatives and friends often become cumbersome and travel to and from 'doctors and rehabilitation' are tiresome. We have documented experience of developing systems and telemedical tools for rehabilitation of stroke victims; tools including serious games, 3D visualization and haptics. For Parkinson's disease we now develop tools for remote assessment of motor function together with experts in clinical care and the ICT industry.

BIO-SKETCH

Martin Rydmark, MD, PhD, is professor of Medical Informatics and Computer Assisted Education. He graduated MD and PhD from the Karolinska Institutet in the early '80s, became associate professsor of anatomy at Gotheburg University (GU) in '85, director of the medical faculty computer laboratory – Mednet – at the Sahlgrenska Academy (GU) in the early '90s, and, finally professor of Medical Informatics and Computer Assisted Education, at GU, in 2010. Presently, he heads a research group/network at GU, focused on ICT based R&D in neurological care and rehabilitation. Earlier research has been in the fields of image analysis, 3D reconstruction, multimedia and educational development.

Smart textiles – a future technology for the fields of disability and rehabilitation?

N-K Persson

Smart Textiles Technology Lab, Swedish School of Textiles, University of Borås, SWEDEN

ABSTRACT

Many things are smart these days; smartphones, smart cars, smart watches, smart materials - and smart textiles. What does this smartness really mean? And what has it to do with rehabilitation and medical devices? In this keynote, Nils-Krister will review the concept and the industry, taking a critical look at some examples of what hitherto have been presented in this genre and discussing ways to go from a gadget phase to a serious technology solving real world problems in many parts of care and medicine. Through a number of examples, the possibilities of smart textiles are shown, conducted with both international and domestic perspectives. The ultimate purpose of the talk will be to convince delegates that smart textiles should be considered an important factor within the fields of disability and rehabilitation.

BIO-SKETCH

Nils-Krister Persson, PhD, is the head of the Smart Textiles Technology Lab (STTL), the technological research body within the Smart Textiles initiative. Smart Textiles is a governmental financed research and innovation cluster in Sweden encouraging new advanced solutions in the textile related industry. Smart Textiles is based at the Swedish School of Textiles at the University of Borås. One of the primary directions of the Smart Textiles initiative is in the area of health and medicine. Nils-Krister is physicist from Lund University and holds a PhD in organic and biomolecular electronics from Linköping University. Research interests include conductive all-polymeric fibres, textile water purification systems, textile photonics for medical applications and dynamic textiles.

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Session I: Elderly Studies/Dementia

Development of a real world simulation to study cognitive, locomotor and metabolic processes in older adults

R Kizony, G Zeilig, PL Weiss, I Baum-Cohen, Y Bahat, E Kodesh,
M Bondi, I Mintz, M Kafri

Sheba Medical Center, Tel Hashomer, ISRAEL

University of Haifa, Haifa, ISRAEL

Tel Aviv University, Tel Aviv, ISRAEL

ABSTRACT

The purpose of this paper was to demonstrate a proof of concept concerning the design and implementation of a simulation that replicates a real world environment in order to evaluate a complex task of shopping within a mall while measuring cognitive, motor and metabolic aspects of the task. The paper presents the experimental protocol and results from four young healthy and two elderly adults who performed the Multiple Errands Test in both simulated and real world settings. These initial findings show the feasibility of the protocol in both environments.

A *screen shot of the simulation's set up at the Center of Advanced Technologies in Rehabilitation, Sheba Medical Center, Tel Hashomer, Israel.*

Kizony, R, Zeilig, G, Weiss, PL, Baum-Cohen, I, Bahat, Y, Kodesh, E, Bondi, M, Mintz, I, and Kafri, M (2014), Development of a real world simulation to study cognitive, locomotor and metabolic processes in older adults, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 1–8, Gothenburg, Sweden, 2–4 Sept. 2014.

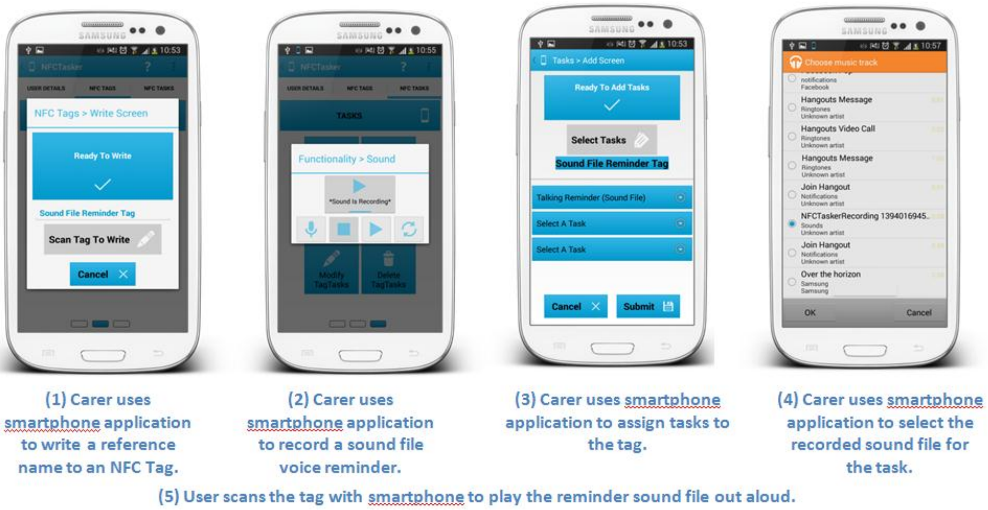
Computerised help information and interaction project for people with memory loss and mild dementia

S Jawaid, R J McCrindle

University of Reading, Whiteknights, Reading, UK

ABSTRACT

People have to perform many tasks and remember many different things during the course of their daily lives. Remembering them all is a challenge for everyone and especially so if a person has age associated memory impairment or some form of dementia. As technologies such as RFID (Radio Frequency Identification) and Near Field Communication (NFC) tags become more cheaply available and more seamlessly integrated into our lives as the Internet of Things (IoT), it makes sense to use these technologies to help people remember information or automate tasks. The CHIIP (Computerised Help Information and Interaction Project) project has created a framework that uses smartphones and sensor technologies to help people perform tasks that are relevant or specific to them quickly and efficiently within their homes or local environment.



Phone setup to enable information or actions to be associated with tags.

Jawaid, S, and McCrindle, RJ (2014), Computerised help information and interaction project for people with memory loss and mild dementia, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 9–18, Gothenburg, Sweden, 2–4 Sept. 2014.

Usability assessment of natural user interfaces during serious games: adjustments for dementia intervention

V Vallejo, I Tarnanas, T Yamaguchi, T Tsukagoshi, R Yasuda, R Müri, U P Mosimann, T Nef

University of Bern, SWITZERLAND

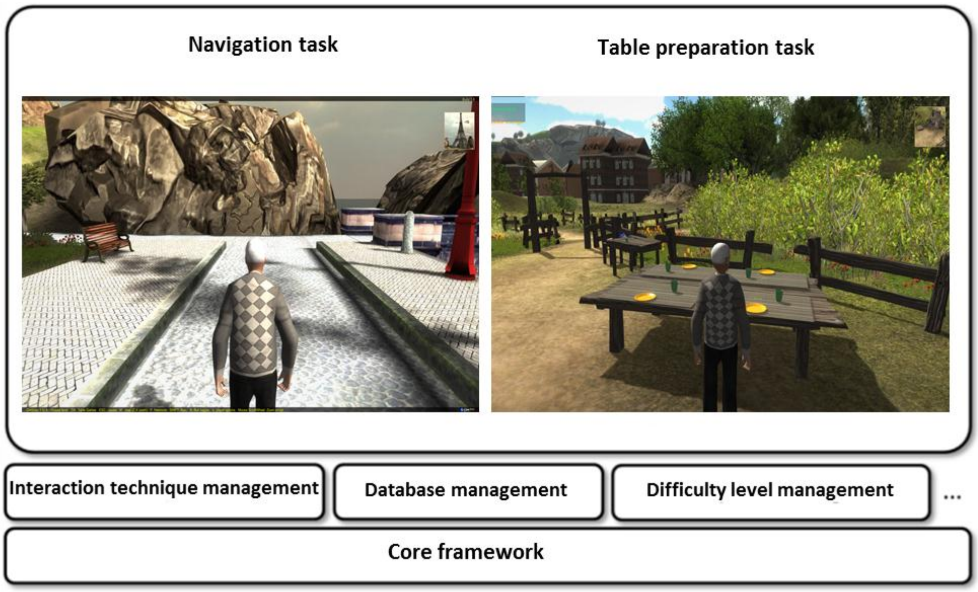
Tokyo University of Science, JAPAN

University Hospital, Inselspital, Bern, SWITZERLAND

University Hospital of Psychiatry, Inselspital, Bern, SWITZERLAND

ABSTRACT

Serious games based rehabilitation program needs a comprehensive and people-centred design for a better efficacy. In most studies benchmarking the computer-interaction interfaces is a prerequisite for adjusting the most appropriate user input for the rehabilitation application. The present study examines a comparison between three natural user interfaces and two standard computer interfaces in two different virtual reality tasks. The results illustrate that the acceptance and user-friendliness of a device regarding the completion of a specific task strongly depends on the task itself and on the abilities of the users.



A system framework of the 3D Virtual Memory.

Vallejo, V, Tarnanas, I, Yamaguchi, T, Tsukagoshi, T, Yasuda, R, Müri, R, Mosimann, UP, and Nef, T (2014), Usability assessment of natural user interfaces during serious games: adjustments for dementia intervention, *Proc. 10th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 19–26, Gothenburg, Sweden, 2–4 Sept. 2014.

Session II: Stroke Rehabilitation

An integrative virtual reality cognitive-motor intervention approach in stroke rehabilitation: a pilot study

A L Faria, A Vourvopoulos, M S Cameirão, J C Fernandes, S Bermúdez i Badia

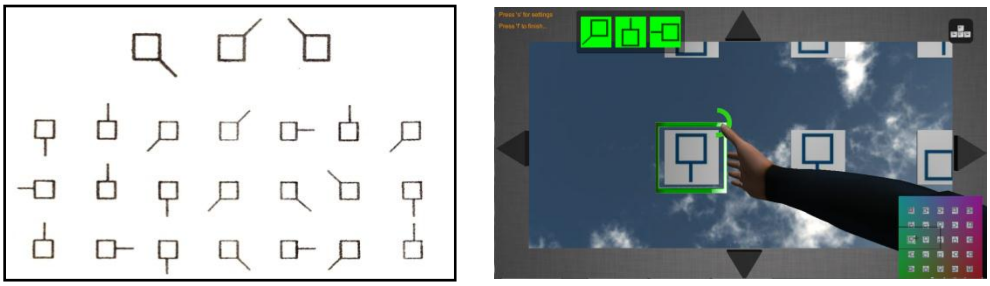
Universidade da Madeira, Funchal, PORTUGAL

Universidade de Coimbra, Coimbra, PORTUGAL

Hospital Nélio Mendonça, Funchal, Madeira, PORTUGAL

ABSTRACT

Stroke is one of the most common causes of acquired disability, leaving numerous adults with cognitive and motor impairments, and affecting patient's capability to live independently. In post-stroke it is imperative to initiate a process of intensive rehabilitation and personalized objectives to maximize functional cognitive and motor recovery. Virtual Reality (VR) technology is being widely applied to rehabilitation of stroke, however, not in an integrative manner. Like traditional rehabilitation, these new tools mostly focus either in the cognitive or in the motor domain, which can take to a reduced impact in the performance of activities of daily living, most of them dual-task. Assuming the existence of cognitive and motor recovery interdependence, RehabNet proposes a holistic approach. Here we present a one-month long pilot study with three stroke patients whose training was a game-like VR version of the Toulouse-Piéron cancellation test, adapted to be performed by repetitive arm reaching movements. A standardized motor and cognitive assessment was performed pre and post intervention. The first results on this intervention support a holistic model for rehabilitation of stroke patients, sustaining interdependence on cognitive and motor recovery. Furthermore, we observed that the impact of the integrative VR approach generalizes to the performance of the activities of daily living.



(a) (b)

Representation of the paper-and-pencil (a) and virtual (b) modalities of the Toulouse-Piéron test.

Faria, AL, Vourvopoulos, A, Cameirão, MS, Fernandes, JC, and Bermúdez i Badia, S (2014), An integrative virtual reality cognitive-motor intervention approach in stroke rehabilitation: a pilot study, *Proc. 10th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 27–35, Gothenburg, Sweden, 2–4 Sept. 2014.

Virtual reality-augmented rehabilitation for patients in sub-acute phase post stroke: a feasibility study

G G Fluet, A Merians, J Patel, A Van Wingerden, Q Qiu, M Yarossi, E Tunik, S Adamovich, S Massood

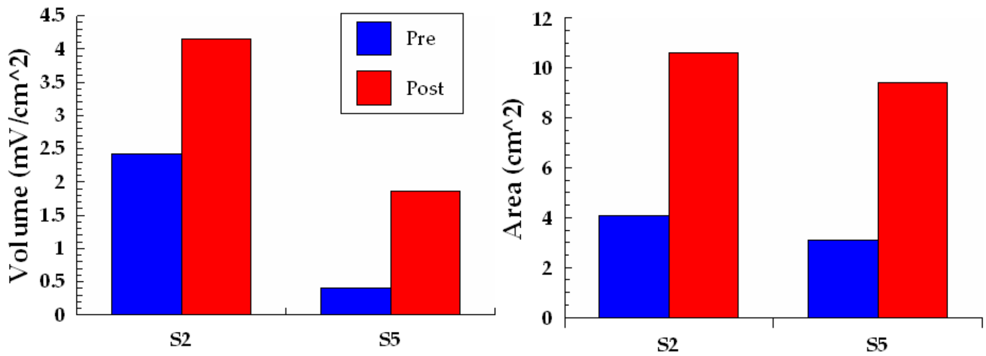
Rutgers University, Newark, NJ, USA

New Jersey Institute of Technology, Newark, NJ, USA

Saint Joseph's Wayne Hospital, Wayne, NJ, USA

ABSTRACT

Upper extremity (UE) rehabilitation is of utmost importance to the achievement of full inclusion and functional independence. Traditionally presented as well as technology-based therapeutic interventions have produced measurable changes in motor function and motor control but fall short of major reductions in disability. Animal models of stroke suggest that the first two weeks to one month post stroke may be a critical time period of increased brain plasticity. This study shows the feasibility of adding one hour of intensive robotic/virtual reality (VR) therapy to on-going rehabilitation in the acute phase of recovery post-stroke. All five of the subjects made substantial improvements in Upper Extremity Fugl-Meyer Assessment (UEFMA) scores (mean improvement = 6 points (SD=2)) as well as improvements in Wolf Motor Function Test (WMFT) time (average decrease = 41% (SD=35) after training with more consistent changes in the proximal arm portions of the WMFT and the UEFMA as well as in upper arm kinematics. Maps of cortical excitability indicate an increase in both the area of activation and the volume of activation of the first dorsal interosseous (FDI) muscle after a two-week training period.



Volume and Area of TMS maps of first dorsal interosseus muscle of paretic hand of two subjects (S2 and S5) measured before and after training.

Fluet, GG, Merians, A, Patel, J, Van Wingerden, A, Qiu, Q, Yarossi, M, Tunik, E, Adamovich, S, Massood, S (2014), Virtual reality-augmented rehabilitation for patients in sub-acute phase post stroke: a feasibility study, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 37–43, Gothenburg, Sweden, 2–4 Sept. 2014.

Session II: Stroke Rehabilitation

Quantifying cognitive-motor interference in virtual reality training after stroke: the role of interfaces

A Vourvopoulos, A L Faria, M S Cameirão, S Bermúdez i Badia

Universidade da Madeira, Funchal, PORTUGAL

Universidade de Coimbra, Coimbra, PORTUGAL

ABSTRACT

Globally, stroke is the second leading cause of death above the age of 60 years, with the actual number of strokes to increase because of the ageing population. Stroke results into chronic conditions, loss of independence, affecting both the families of stroke survivors but also public health systems. Virtual Reality (VR) for rehabilitation is considered a novel and effective low-cost approach to re-train motor and cognitive function through strictly defined training tasks in a safe simulated environment. However, little is known about how the choice of VR interfacing technology affects motor and cognitive performance, or what the most cost-effective rehabilitation approach for patients with different prognostics is. In this paper we assessed the effect of four different interfaces in the training of the motor and cognitive domains within a VR neurorehabilitation task. In this study we have evaluated the effect of training using 2-dimensional and 3-dimensional as well as traditional and natural user interfaces with both stroke survivors and healthy participants. Results indicate that 3-dimensional interfaces contribute towards better results in the motor domain at the cost of lower performance in the cognitive domain, suggesting the use 2-dimensional natural user interfaces as a trade-off. Our results provide useful pointers for future directions towards a cost-effective and meaningful interaction in virtual rehabilitation tasks in both motor and cognitive domains.

2-dimensional (a) and 3-dimensional (b) experimental setups. Inset images show the user's position relative to VR system and the allowed movements.

Vourvopoulos, A, Faria, AL, Cameirão, MS, and Bermúdez i Badia, S (2014), Quantifying cognitive-motor interference in virtual reality training after stroke: the role of interfaces, *Proc. 10th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 45–53, Gothenburg, Sweden, 2–4 Sept. 2014.

Cognitive stimulation through mHealth-based program for patients with Alcohol Dependence Syndrome – a randomized controlled study

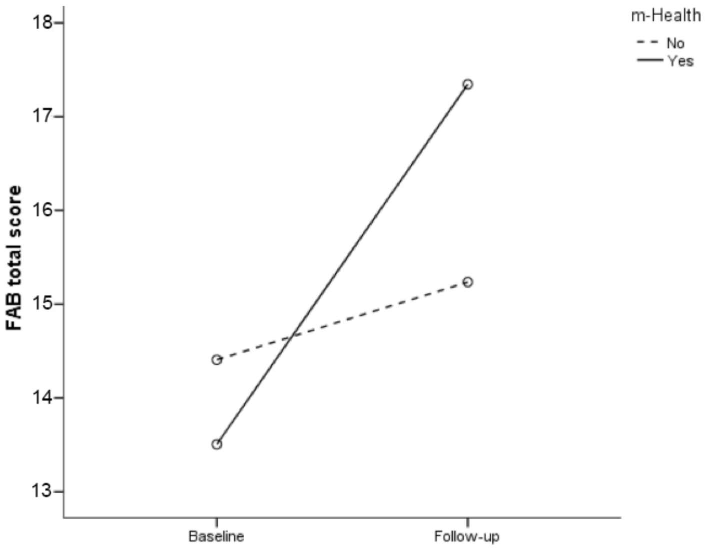
P Gamito, J Oliveira, P Lopes, R Brito, D Morais, S Rebelo,
D Silva, C Caçôete, A Deus

Lusophone University, Lisbon, PORTUGAL

São João de Deus Institute, Sintra, PORTUGAL

ABSTRACT

Alcohol abuse can impact on general cognitive functioning and more particularly on frontal lobe functions. One option available to reduce this impact may rest on rehabilitation paradigms that include cognitive stimulation programmes. This paper reports on a randomized controlled study where two sample of patients with alcohol dependence syndrome where enrolled: 1) on a mHealth-based cognitive stimulation program (CSP) within alcohol dependence treatment (experimental group) and 2) on the alcohol dependence treatment without CSP (control group). The CSP mHealth applications consisted on a serial of serious games designed to stimulate frontal lobe functions. Assessment was conducted with the Mini-Mental State Examination and the Frontal Assessment Battery. After 10 stimulation sessions the experimental group evidenced a significant improvement on frontal-lobe functioning when compared with the control group. As expected, no differences on general cognitive functioning were found between groups.



Improvements in FAB scores at follow-up for m-Health group.

Gamito, P, Oliveira, J, Lopes, P, Brito, R, Morais, D, Rebelo, S, Silva, D, Caçôete, C, and Deus, A (2014), Cognitive stimulation through mHealth-based program for patients with Alcohol Dependence Syndrome – a randomized controlled study, *Proc. 10th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 55–61, Gothenburg, Sweden, 2–4 Sept. 2014.

Virtual reality exposure for trauma and stress-related disorders for city violence crime victims

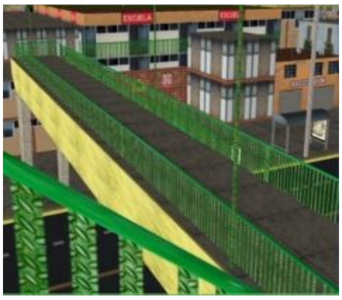
G Cárdenas-López, A de la Rosa, R Durón, X Durán

National Autonomous University of Mexico, Mexico City, MEXICO

ABSTRACT

The criminal violence is attached with mental health problems as depression and substance use and abuse. However one of most important psychological problems linked with the victims of violence is Posttraumatic Stress Disorder (PSTD) and Acute Stress Disorder (ASD). In Mexico, according to the ICESI in 2012, 11% (6,800/for each 100 thousands of habitants) of the population over 18 years experienced a crime. One in four of the people victim of violence develops PSTD symptoms. Due to this socially relevant problem and based on the efficacy of Virtual Reality (VR) treatments, it is important to design treatments involving the use of VR because it can help overcome some of the limitations of traditional therapy using exposure. The present study shows preliminary results of efficacy or virtual reality treatment for PTSD and ASD for crime violence. The clinical sample was conformed for 9 participants from city of Mexico, 6 participants with PTSD diagnoses and 3 participants with ASD diagnoses, aged between 18 and 65. All participants gave informed consent to participate. Treatment was delivered in 90 min individual sessions conducted once a week. Three virtual scenarios for PTSD exposure treatment were used. Improvement was seen in measures of stress, anxiety and depression in both treatment groups, which confirms the clinical efficacious for this technique to treat stress-related disorders.

City view.



Bridge view.

Taxi view.

Cárdenas-López, G, de la Rosa, A, Durón, R, and Durán, X (2014), Virtual reality exposure for trauma and stress-related disorders for city violence crime victims, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 63–71, Gothenburg, Sweden, 2–4 Sept. 2014.

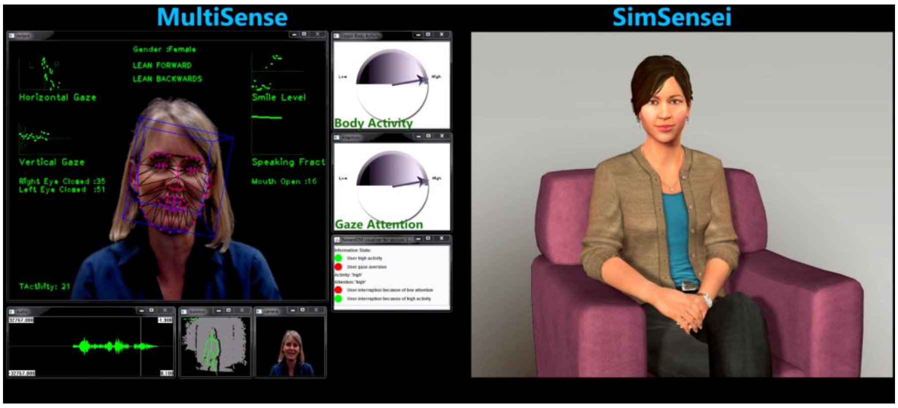
Detection and computational analysis of psychological signals using a virtual human interviewing agent

A A Rizzo, S Scherer, D Devault, J Gratch, R Artstein, A Hartholt, G Lucas, S Marsella, F Morbini, A Nazarian, G Stratou, D Traum, R Wood, J Boberg, L-P Morency

Institute for Creative Technologies, University of Southern California, USA

ABSTRACT

It has long been recognized that facial expressions, body gestures and vocal features/prosody play an important role in human communication signaling. Recent advances in low cost computer vision and sensing technologies can now be applied to the process of sensing such behavioral signals and from them, making meaningful inferences as to user state when a person interacts with a computational device. Effective use of this additive information could serve to enhance human interaction with virtual human (VH) agents and for improving engagement in Telehealth/Teletherapy approaches between remote patients and care providers. This paper will focus on our current research in these areas within the DARPA-funded "Detection and Computational Analysis of Psychological Signals" project, with specific attention to our SimSensei application use case. SimSensei is a virtual human platform able to sense real-time audio-visual signals from users interacting with the system. It is specifically designed for health care support and is based on years of expertise at ICT with virtual human research and development. The platform enables an engaging face-to-face interaction where the virtual human automatically reacts to the estimated user state and intent of the user through vocal parameters and gestures. Much like non-verbal behavioral signals have an impact on human to human interaction and communication, SimSensei aims to capture and infer from user's non-verbal communication to improve engagement between a VH-human and a user. The system can also quantify sensed signals over time that could inform diagnostic assessment within a clinical context.



SimSenswi.

Rizzo, AA, Scherer, S, Devault, D, Gratch, J, Artstein, R, Hartholt, G, Lucas, G, Marsella, S, Morbini, F, Nazarian, A, Stratou, G, Traum, D, Wood, R, Boberg, J, and Morency, L-P (2014), Detection and computational analysis of psychological signals using a virtual human interviewing agent, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 73–82, Gothenburg, Sweden, 2–4 Sept. 2014.

Session III: Behavioural and Psychological Disorders

Cravings in a virtual reality room paired with chocolate predict eating disorder risk

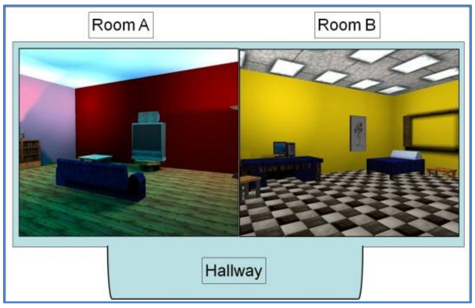
R S Astur, A W Carew, A Palmisano, B E Deaton,
F Kuhney, R Niezrecki, M Santos

University of Connecticut, Storrs, CT, USA

Connecticut Childrens Medical Center, Hartford, CT, USA

ABSTRACT

Pavlovian conditioning is a major factor in drug and food addictions. Previously, we have shown in humans that we can reliably establish a conditioned place preference to a virtual reality (VR) room that is paired with real life food reward. We examined whether the strength of this conditioned place preference is related to eating disorder risk. 31 food-restricted female undergraduates were recruited and placed into a VR environment consisting of 2 visually distinct rooms connected by a hallway. Participants underwent 6 pairing sessions in which they were locked into one of the two rooms and explored the VR environment. Room A was paired with real-life M&Ms for 3 sessions, and Room B was paired with no food for 3 sessions. After the conditioning, a test session was given in which participants were given free access to the entire VR environment with no food present. Additionally, participants completed a standard assessment of eating disorder risk, the Eating Attitudes Test (EAT-26). We observed a conditioned place preference only for the participants who were in the top 50 percentile for hunger. Self-reported hunger rating was significantly correlated with amount of time in the room paired with food. In regards to the eating attitudes, we observed that the higher the eating disorder risk, as evidenced by higher scores on the dieting subscale, and as evidenced by higher total risk scores, the lower they rated the room paired with no food. This suggests a unique conflict whereby stimuli that are not food associated are rated as less enjoyable, particularly the higher the risk for an eating disorder. Hence, novel measures and associations from a brief conditioning paradigm predict eating disorder risk and may suggest some implicit conflicts and processes involved in people with eating disorders. Future studies will examine people with eating disorders more directly as well as will examine whether these measures can direct treatment strategies and predict treatment success.



Both rooms were identical in shape, but contained different items, colors, patterns, etc.

Astur, RS, Carew, AW, Palmisano, A, Deaton, BE, Kuhney, F, Niezrecki, R, and Santos, M (2014), Cravings in a virtual reality room paired with chocolate predict eating disorder risk, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 83–88, Gothenburg, Sweden, 2–4 Sept. 2014.

Session IV: Upper Limb Rehabilitation I

Analysis of arm movement strategy in virtual catching task

T Yamaguchi, N Ishiura, P Richard, D A Foloppe,
F Veaux, M Dinomais, S Nguyen

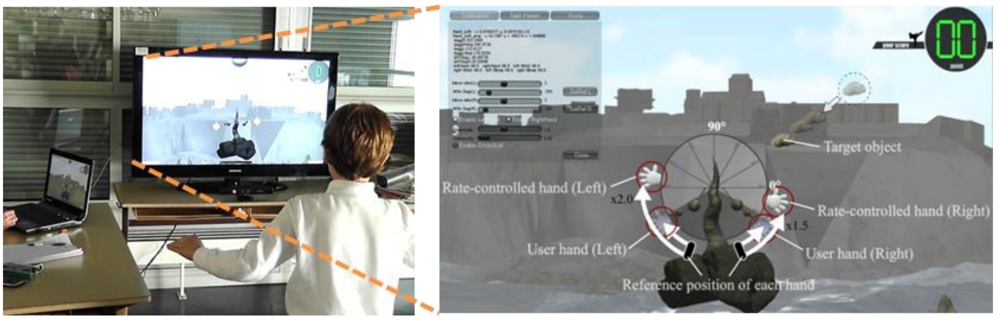
Tokyo University of Science, JAPAN

Université d'Angers, Angers, FRANCE

Centre les Capucins, Angers, FRANCE

ABSTRACT

In this paper, we explored how the arm movement pattern as well as the related strategy of the children with Cerebral Palsy (CP) and the healthy children can be changed in the virtual catching task on a previously proposed rehabilitation system. We recruited 50 healthy children from elementary school, and 3 children with CP as subjects to classify their arm movement pattern/strategy. As a result of the classification, we identified three arm movement stages: Initial position, Reaching path, and Waving form, as well as movement pattern strategy under each movement stage. Based on the classified pattern, we compared the differences in the time series changes of movement strategy between healthy children and the children with CP. The results show there is a significant difference in the strategy of arm movements in the Initial position between healthy and CP children.



An experimental setting of rehabilitation application (Left), and Screenshot of rehabilitation application – Control/Display 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 (Right).

Yamaguchi, T, Ishiura, N, Richard, P, Foloppe, DA, Veaux, F, Dinomais, M, and Nguyen, S (2014), Analysis of arm movement strategy in virtual catching task, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 89–97, Gothenburg, Sweden, 2–4 Sept. 2014.

Functional improvement of hemiparetic upper limb after a virtual reality-based intervention with a tabletop system and tangible objects

R Lloréns, C Colomer, E Noé, M Ortega, M Alcañiz

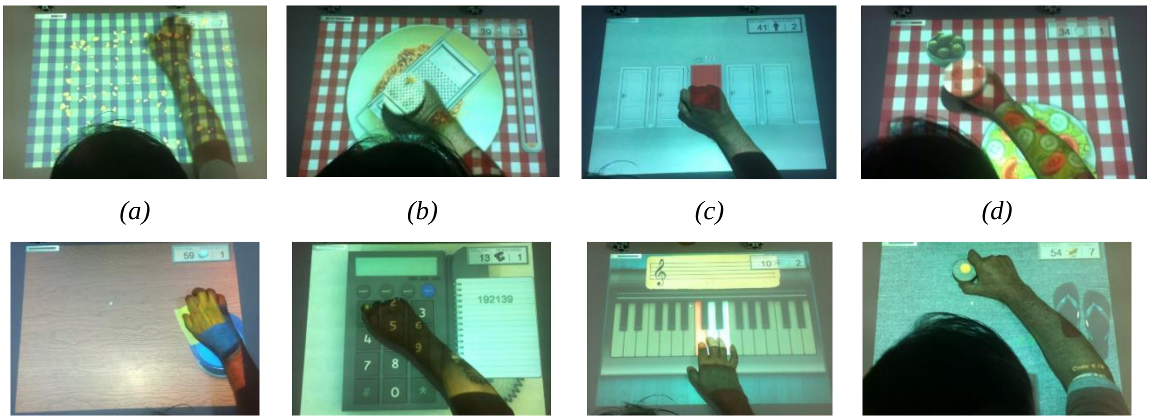
Universitat Politècnica de València, SPAIN

Hospitales NISA Valencia al Mar y Sevilla, Valencia, SPAIN

Univesity of Jaume I, Castellón, SPAIN

ABSTRACT

Rehabilitation of the hemiparetic upper limb after stroke is a common challenge for neurorehabilitation units. Recent advances in behavioural neuroscience and neuroimaging techniques have provided current insights of brain plasticity mechanisms that support the functional improvement after an injury to the brain. Different interventions have provided evidence of improvement associated to cortical reorganization. Initial studies report the benefits of virtual reality interventions to recreate enriched and controlled environments that promote brain plasticity mechanisms. This paper presents a novel virtual reality-based tabletop system that focuses on the motor learning principles to promote functional improvement of the hemiparetic upper limb in chronic individuals with stroke. The system allows users to perform a set of exercises that train different movements and skills interacting with or without tangible objects. A preliminary study to determine the clinical effectiveness and acceptance of a virtual reality-based intervention is provided.



(a) *(b)* *(c)* *(d)*

(e) *(f)* *(g)* *(h)*

Participant interacting with the UMBRELLA system.

Lloréns, R, Colomer, C, Noé, E, Ortega, M, and Alcañiz, M (2014), Functional improvement of hemiparetic upper limb after a virtual reality-based intervention with a tabletop system and tangible objects, *Proc. 10th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 99–107, Gothenburg, Sweden, 2–4 Sept. 2014.

Arm prosthesis simulation on a virtual reality L-shaped workbench display system using a brain computer interface

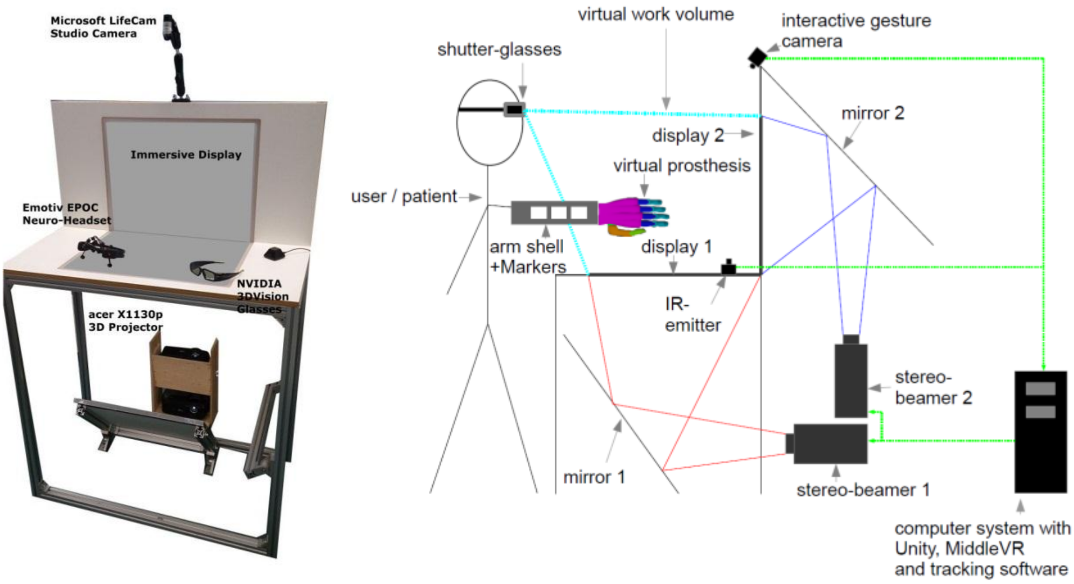
G Heisenberg, Y A Rezaei, T Rothdeutsch, W Heiden

University of Applied Sciences, Wiesbaden, GERMANY

University of Applied Sciences, Sankt Augustin, GERMANY

ABSTRACT

The work being described in this paper is the result of a cooperation project between the Institute of Visual Computing at the Bonn-Rhein-Sieg University of Applied Sciences, Germany and the Laboratory of Biomedical Engineering at the Federal University of Uberlândia, Brazil. The aim of the project is the development of a virtual environment based training simulator which enables for better and faster learning the control of upper limb prostheses. The focus of the paper is the description of the technical setup since learning tutorials still need to be developed as well as a comprehensive evaluation still needs to be carried out.



System setup and L-shaped workbench at the Bonn-Rhein-Sieg University. The right part of the image shows all components being used. The virtual prosthesis model is shown as an extension of the user's arm shell with markers.

Heisenberg, G, Rezaei, YA, Rothdeutsch, T, and Heiden, W (2014), Arm prosthesis simulation on a virtual reality L-shaped workbench display system using a brain computer interface, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 109–117, Gothenburg, Sweden, 2–4 Sept. 2014.

Session V: Body Movement Training

Effect of the Oculus Rift head mounted display on postural stability

P Epure, C Gheorghe, T Nissen, L O Toader, A N Macovei, S S M Nielsen,
D J Rosengren Christensen, A L Brooks, E Petersson Brooks

Aalborg University, Esbjerg, DENMARK

ABSTRACT

This study explored how a HMD-experienced virtual environment influences physical balance of six balance-impaired adults 59-69 years-of-age, when compared to a control group of eight non-balance-impaired adults, 18-28 years-of-age. The setup included a Microsoft Kinect and a self-created balance board controlling a skiing game. Two tests were conducted: full-vision versus blindfolded and HMD versus monitor display. Results were that five of the six balance-impaired adults and six of the eight non-balance-impaired adults showed higher degree of postural stability while using a monitor display. Conclusions are that HMD, used in this context, leads to postural instability.

Spider 8 data logger (left) and balance board (right).

Epure, P, Gheorghe, C, Nissen, T, Toader, LO, Macovei, AN, Nielsen, SSM, Rosengren Christensen, DJ, Brooks, AL, and Petersson Brooks, E (2014), Effect of the Oculus Rift head mounted display on postural stability, *Proc. 10th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 119–127, Gothenburg, Sweden, 2–4 Sept. 2014.

Session V: Body Movement Training

Virtual reality system for the enhancement of mobility in patients with chronic back pain

B Bolte, M de Lussanet, M Lappe

University of Münster, GERMANY

ABSTRACT

Back pain is among the most common health problems in the western world. While surgery can reduce pain and disability for patients with symptoms specific to spinal degeneration, for chronic back pain (CBP) patients exist a variety of therapeutic interventions, which are, unfortunately, not very effective. In addition, CBP patients tend to develop a fear of movement (kinesiophobia) and stiffness of the trunk that probably lead to further problems due to reduced physical activity. To address these problems, we propose a virtual reality system using head-mounted displays for the enhancement of mobility in CBP patients. We manipulate the visual feedback to change the motor behavior of participants by applying gains to alter the weight with which neck, back and hip rotations contribute to the orientation of the virtual camera. Users will not notice the manipulation if the gains are sufficiently small. In an evaluation study we showed that our approach has the potential to increase back movement amplitudes in control and CBP participants. Although we have used a specific task, the big advantage of our method is that any task involving body rotations can be used, thereby providing the opportunity to tailor the task to a patient's specific preference or need.

(a) (b)

Illustration of (a) the instrumentation and (b) the virtual basketball arena used for the evaluation study. The participant is wearing the head-mounted display, with a fixed infrared marker, on which the virtual basketball arena is shown. Yellow circles indicate the positions of the orientation trackers.

Bolte, B, de Lussanet, M, and Lappe, M (2014), Virtual reality system for the enhancement of mobility in patients with chronic back pain, *Proc. 10th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 129–137, Gothenburg, Sweden, 2–4 Sept. 2014.

Session V: Body Movement Training

The application of enhanced virtual environments for co-located childhood movement disorder rehabilitation

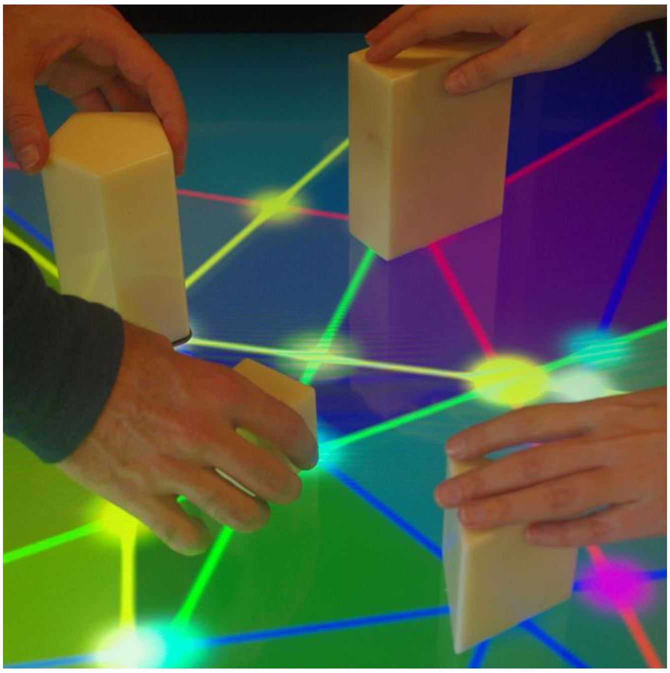
N H Mumford, J Duckworth, P H Wilson

Australian Catholic University, Melbourne, AUSTRALIA

RMIT University, Melbourne, AUSTRALIA

ABSTRACT

In this paper we discuss potential benefits and future directions in virtual reality rehabilitation for co-located motor training in children with developmental movement disorders. We discuss the potential for co-located VR to promote participation using cooperative virtual environments, facilitate social learning, and quantify levels of social interaction. We pay particular attention to the capacity of co-located systems to enhance levels of participation and the psychosocial outcomes of VR therapy. Finally, we offer directions for future research.



Two participants playing a musical tabletop game together using tangible user interfaces..

Mumford, NH, Duckworth, J, and Wilson, PH (2014), The application of enhanced virtual environments for co-located childhood movement disorder rehabilitation, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 139–145, Gothenburg, Sweden, 2–4 Sept. 2014.

Session V: Body Movement Training

Towards a mobile exercise application to prevent falls: a participatory design process

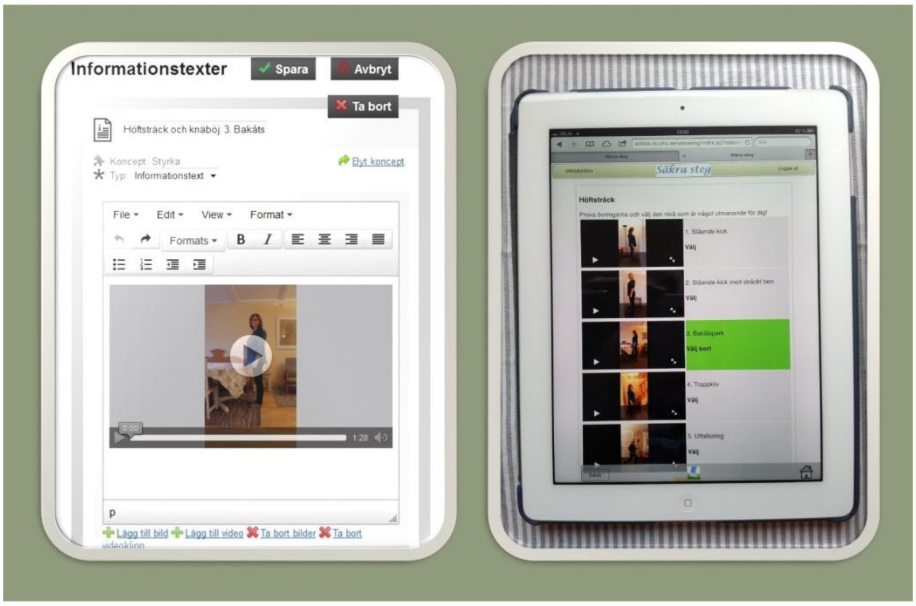
M Sandlund, H Lindgren, P Pohl, A Melander-Wikman,
B Bergvall-Kåreborn, L Lundin-Olsson

Umeå University, SWEDEN

Luleå University of Technology, SWEDEN

ABSTRACT

In this cross-disciplinary project senior citizens and researchers participated in the collaborative design and development of a mobile exercise application to prevent falls. The methods Form-IT and Participatory and Appreciative Action and Reflection were applied in a series of workshops, facilitating the creation of new knowledge and a socio-technical platform for an end-user development process. The participation of the older adults was key to understanding the broad range of preferences and motivational aspects. The outcomes emerged into prototypes, which were composed using the ACKTUS platform for end-user development, resulting in a dynamic application, easily adaptable to future needs and studies.



The ACKTUS platform was used to model the content and design the interaction in the prototypes, which allowed the participants to test hands-on. Through ACKTUS the responsible physiotherapist researchers are able to modify and further develop the application.

Sandlund, M, Lindgren, H, Pohl, P, Melander-Wikman, A, Bergvall-Kåreborn, B, and Lundin-Olsson, L (2014), Towards a mobile exercise application to prevent falls: a participatory design process, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 147–154, Gothenburg, Sweden, 2–4 Sept. 2014.

Session VI: Evaluating Technologies

User evaluation of a virtual rehabilitation system during reaching exercises: a pilot study

M Al-Amri, D Abásolo, S Ghoussayni, D Ewins

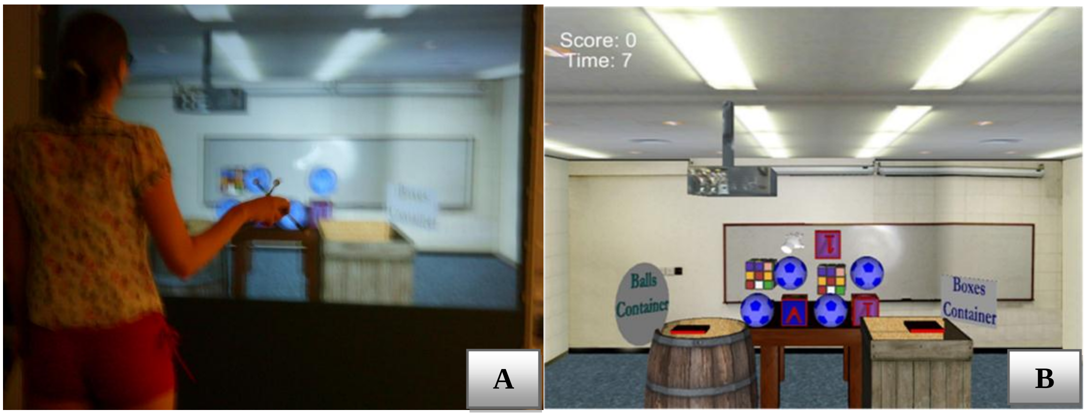
Cardiff University, UK

University of Surrey, UK

Queen’s Mary Hospital, Roehampton, UK

ABSTRACT

The aim of this paper was to evaluate the practicality of the Surrey Virtual Rehabilitation System (SVRS) for reaching exercises with children with CP. Five potential users or operators (two children with CP, a physiotherapist, and two clinical engineers) participated in the study. Using 11 closed-ended questions and an open discussion, the feedback collected indicates that the participants were generally positive about the practicality of the SVRS. Outcome measures obtained from data gathered during the session suggest that the SVRS can provide clinically relevant feedback on the performance of patients for themselves and their treating clinicians. In conclusion, the SVRS seems to be practical for rehabilitation purposes and further development and evaluation are warranted.



An able-bodied volunteer using the SVRS to perform the second reaching exercise. A: during the actual test and B: a screenshot of the VR environment..

Al-Amri, M, Abásolo, D, Ghoussayni, S, and Ewins, D (2014), User evaluation of a virtual rehabilitation system during reaching exercises: a pilot study, *Proc. 10th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 155–162, Gothenburg, Sweden, 2–4 Sept. 2014.

Locating objects in virtual reality – the effect of visual properties on target acquisition in unrestrained reaching

V Powell, W A Powell

University of Portsmouth, UK

ABSTRACT

Locating objects in virtual space is not the same as locating them in physical space. The visual properties of the virtual object can affect the perception of its spatial location, and hence the ability to accurately co- locate the hand and the object. This paper presents an investigation into the effects of object geometry and proximity brightness cues on the time-to-target of a virtual reality reaching and grasping task. Time-to-target was significantly affected by object geometry, but not by brightness cues. We conclude that object geometry needs to be carefully considered for applications where accurate co-location of hand and object are important.

The virtual orchard used in the study.

Powell, V, and Powell, WA (2014), Locating objects in virtual reality – the effect of visual properties on target acquisition in unrestrained reaching, *Proc. 10th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 163–171, Gothenburg, Sweden, 2–4 Sept. 2014.

Subjective perceptions when using motion tracking systems – a comparison among healthy subjects, individuals post-stroke, and therapists

R Lloréns, A Borrego, E Parra, V Naranjo, E Noé, M Alcañiz

Universitat Politècnica de València, SPAIN

Hospitales NISA Valencia al Mar y Sevilla, Valencia, SPAIN

Univesity of Jaume I, Castellón, SPAIN

ABSTRACT

Different tracking technologies allow users to interact with virtual reality environments. Most research regarding tracking systems has focused on studying their performance parameters, mainly accuracy. However, even though subjective parameters also determine the responses evoked by the virtual reality experience, least efforts have been made to study their influence. The subjective perceptions of healthy subjects, individuals post-stroke, and physical therapists after using three tracking technologies (optical, electromagnetic, and skeleton tracking) to interact with a virtual rehabilitation exercise were collected via questionnaire. Results showed that subjective perceptions and preferences are far from being constant among different populations, thus suggesting that these considerations, together with the performance parameters, should be taken into account when designing a rehabilitation system.

Tracking systems under study: optical; electromagnetic; and skeleton tracking.

Lloréns, R, Borrego, A, Parra, E, Naranjo, V, Noé, E, and Alcañiz, M (2014), Subjective perceptions when using motion tracking systems – a comparison among healthy subjects, individuals post-stroke, and therapists, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 173–180, Gothenburg, Sweden, 2–4 Sept. 2014.

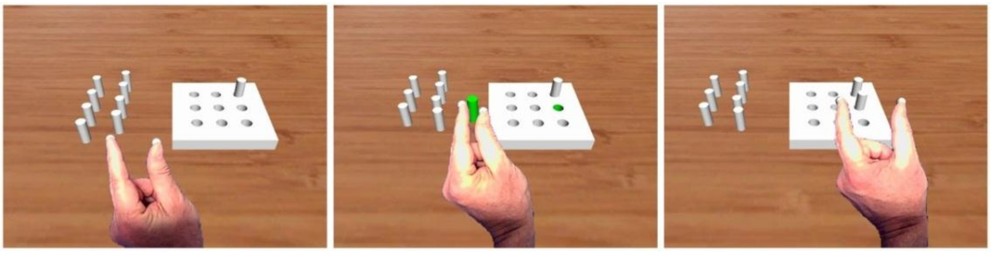
Virtualising the nine hole peg test of finger dexterity

J Collins, S Hoermann, H Regenbrecht

University of Otago, Dunedin, NEW ZEALAND

ABSTRACT

Using Virtual and Augmented Reality (VR/AR) approaches in physical rehabilitation can lead to better controlled, more client motivating, and more flexible forms of therapy. The Nine Hole Peg Test (NHPT) is a standard instrument in physiotherapy to practice and assess a patient's hand motor control abilities. A physical, wooden or plastic board with nine holes and cylindrical shaped pegs are used to perform this task. There are only limited ways of varying the degree of difficulty or to precisely measure progress with this physical setup. This study presents the development of a VR/AR version of the NHPT and evaluates the usability of three versions: (1) the real life wooden version, (2) a video-mediated version and (3) a computer-generated AR version built from low-cost off-the-shelf components. Our results show that all three conditions were successfully completed by all participants with the highest measured performance and perceived usability still achieved in the real life situation. This indicates that the implementation of currently available low-cost, off-the-shelf components is not yet reliable enough to suggest its use for therapeutic exercises or assessments that require very fine finger level interaction.



Reaching for a virtual peg (left), moving it towards its destination (centre) and releasing it (right).

Collins, J, Hoermann, S, and Regenbrecht, H (2014), Virtualising the nine hole peg test of finger dexterity, *Proc. 10th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 181–188, Gothenburg, Sweden, 2–4 Sept. 2014.

Session VII: Upper Limb Rehabilitation II

Development of a new scoring system for bilateral upper limb function and performance in children with cerebral palsy using the MIRA interactive video games and the Kinect sensor

I M Moldovan, A D Călin, A C Cantea, L A Dascălu, C A Mihaiu,
O Ghircău, S Onac, O Rîză, R A Moldovan, L V Pop

Socio-medical services complex “Maria Beatrice”, Alba-Iulia, ROMANIA

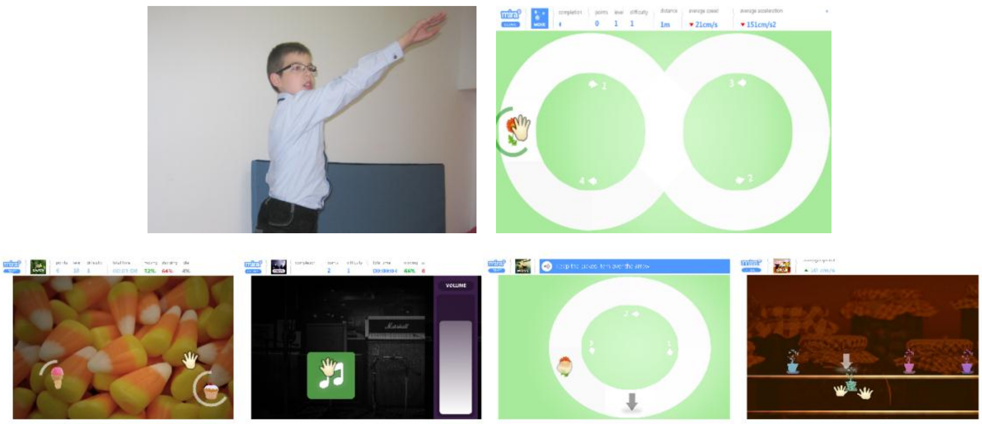
MIRA REHAB LIMITED, London, UK

Alba-Iulia Emergency County Hospital, ROMANIA

“Iuliu Hațieganu” University of Medicine and Pharmacy, Cluj-Napoca, ROMANIA

ABSTRACT

The aim of the study is to develop a reliable and valid occupational therapy scoring system for the assessment of bilateral upper limb function and performance in children with cerebral palsy (CP) using adapted MIRA (Medical Interactive Rehabilitation Assistant) interactive video games and the Kinect 360 Xbox sensor. MIRA is a software platform that uses the Kinect 360 motion sensor to interact with several video games adapted for children with cerebral palsy. 16 healthy children and 11 children diagnosed with cerebral palsy played four MIRA games that generate three performance quantifiers: distance (m), average acceleration (m/s2) and score (points). The reliability and the validity tests performed suggest that the scoring of the MIRA testing schedule is a reliable and valid occupational therapy tool for the assessment of bilateral upper limb function and performance in children with cerebral palsy.



Snapshots of the MIRA video-games; in order: a child with cerebral palsy while playing, Move - infinit path, Catch, Follow, Move - circle path and Grab. A short movie of MIRA testing schedule is available at http://www.mariabeatrice.ro/mira/mira-testing-schedule.

Moldovan, IM, Călin, AD, Cantea, AC, Dascălu, LA, Mihaiu, CA, Ghircău, O, Onac, S, Rîză, O, Moldovan, RA, and Pop, LV (2014), Development of a new scoring system for bilateral upper limb function and performance in children with cerebral palsy using the MIRA interactive video games and the Kinect sensor, *Proc. 10th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 189–196, Gothenburg, Sweden, 2–4 Sept. 2014.

Session VII: Upper Limb Rehabilitation II

Evaluating the Microsoft Kinect for use in upper extremity rehabilitation following stroke as a commercial off the shelf gaming system

L Shires, D J Brown, N Sherkat, J Lewis, P J Standen

Nottingham Trent University, UK

University of Nottingham, UK

ABSTRACT

Motion controlled video games have been shown to have a positive effect for physical rehabilitation on the upper extremity in stroke survivors when combined with conventional physical therapy. While much research in this area has worked with bespoke systems and games, some research has been done into using commercial off the shelf gaming systems (COTS) for use in upper extremity stroke rehabilitation. As COTS systems are designed to be used in the home they offer the possibility of providing survivors with low cost systems that they can use to carry out rehabilitation at home. The Microsoft Kinect for the Xbox360 is a multimodal gaming peripheral used to drive a full body skeletal pose estimation system. This allows users to interact with games using bodily motions and gestures. Unlike other current motion controlled gaming systems the Kinect is marker-less so does not require the user to hold or wear any peripherals. A list of important joint motions and movement synergies were identified by looking at leading stroke motor function tests for the upper limb. These have been verified by working with Occupational Therapists. A study group of Occupational and Physiotherapists were asked to record their experience of playing three Kinect mini-games from the Kinect Sports title and evaluate them with respect to their motor function requirements and exertion for each identified joint motion. Quality information was also gathered relating to the perceived usability and safety issues that could arise by presenting the device to a stroke survivor. Kinect provides opportunities for gross arm movement exercise, while the requirement for highly raised arm movements will present a potential barrier for stroke users. Fine motor control movements of the hand and fingers are not tracked sufficiently for effective rehabilitation of the hand. A probable risk of falling while using the Kinect, and potential injury from overexerting the impaired limb while playing existing games were also identified. We conclude that as the experience have been designed for able bodied users the games present significant barriers for using Kinect as a COTS system for stroke rehabilitation.

Kinect Sports for the Xbox360. [Rare, 2014].

Shires, L, Brown, DJ, Sherkat, N, Lewis, J, and Standen, PJ (2014), Evaluating the Microsoft Kinect for use in upper extremity rehabilitation following stroke as a commercial off the shelf gaming system, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 197–204, Gothenburg, Sweden, 2–4 Sept. 2014.

Adapting a humanoid robot for use with children with profound and multiple disabilities

P J Standen, D J Brown, J Hedgecock, J Roscoe, M J Galvez Trigo, E Elgajiji

University of Nottingham, UK

Nottingham Trent University, UK

ABSTRACT

With all the developments in IT for people with disabilities, few interventions have been designed for people with profound and multiple disabilities as there is little incentive for companies to design and manufacture technology purely for a group of consumers without much buying power. A possible solution is therefore to identify mainstream technology that, with adaptation, could serve the purposes required by those with profound and multiple disabilities. Because of its ability to engage the attention of young children with autism, the role of a humanoid robot was investigated. After viewing a demonstration, teachers of pupils with profound and multiple disabilities described actions they wished the robot to make in order to help nominated pupils to achieve learning objectives. They proposed a much wider range of suggestions for using the robot than it could currently provide. Adaptations they required fell into two groups: either increasing the methods through which the robot could be controlled or increasing the range of behaviours that the robot emitted. These were met in a variety of ways but most would require a degree of programming expertise above that possessed by most schoolteachers.

ST repeating back to the robot the utterance it has just emitted.

Standen, PJ, Brown, DJ, Hedgecock, J, Roscoe, J, Galvez Trigo, MJ, and Elgajiji, E (2014), Adapting a humanoid robot for use with children with profound and multiple disabilities, *Proc. 10th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 205–211, Gothenburg, Sweden, 2–4 Sept. 2014.

Session VIII: Cognitive Training

Assessment of convalescent brain-damaged patients using a virtual shopping test with different task difficulties

S Okahashi, H Mizumoto, A Komae, K Ueno, M Yokoyama,
A Nagano, K Seki, T Futaki, Z W Luo

Kyoto University, Kyoto, JAPAN

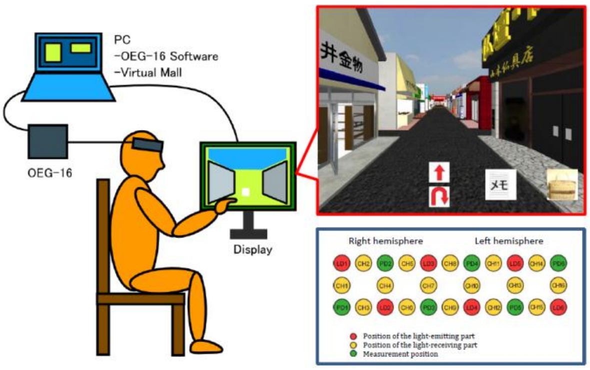
Kobe University, Kobe, JAPAN

Nishi Memorial Port Island Rehabilitation Hospital, Kobe, JAPAN

Ritsumeikan University, Shiga, JAPAN

ABSTRACT

We developed a Virtual Shopping Test for realistic cognitive assessment using virtual reality technology. The objective of this study was to investigate differences in task performance, brain activation, and subjective assessments in relation to the task difficulty level. Subjects were asked to buy two specific items in Task 1, four items in Task 2, and six items in Task 3 at a virtual mall. The tasks and questionnaires were conducted by convalescent brain-damaged patients and healthy adults. Hemodynamic changes in the prefrontal cortex (PFC) during activation due to the tasks were examined using functional near-infrared spectroscopy. The mean total time was longer for the patients than for the healthy subjects in all tasks. PFC responses in the patients were greater in Task 2 than in Task 1. The patients subjectively evaluated these tasks as more difficult than healthy adults. Although task performance as well as PFC responses were not significantly changed in the healthy adults, they could subjectively evaluate differences between the three task levels, whereas the patients could not, which indicated that patients could not clearly distinguish between differences in the difficulty of the tasks performed. Taken together, the results suggest that the difficulty of the 4-item shopping task may have been sufficient to cause brain activation in the brain-damaged patients.



Experimental system with a screenshot of the Virtual Shopping Test-Revised (VST-R) and fNIRS channel arrangement on the forehead.

Okahashi, S, Mizumoto, H, Komae, A, Ueno, K, Yokoyama, M, Nagano, A, Seki, K, Futaki, T, and Luo, ZW (2014), Assessment of convalescent brain-damaged patients using a virtual shopping test with different task difficulties, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 213–220, Gothenburg, Sweden, 2–4 Sept. 2014.

Case study series using brain-training games to treat attention and memory following brain injury

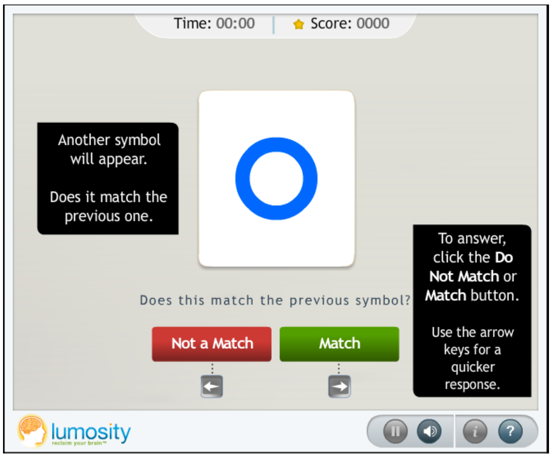
B B Connor, C Shaw

Independent Practice in Neuropsychology, Nevada City, CA, USA

Sierra Nevada Memorial Hospital, Grass Valley, CA, USA

ABSTRACT

Rehabilitation following acquired brain injury typically focuses on regaining use of the affected lower and upper limbs. Impairment of cognitive processes, however, is predictive of rehabilitation outcomes. Cognitive activities have become more readily accessible to the home user through web-based games that engage brain functions often disrupted by acquired brain injury. With cognitive testing, it is possible to "prescribe" brain training that targets the specific cognitive functions disrupted by an individual's acquired brain injury. Previous research has shown that individuals with acquired brain injury have difficulty finding the time to train on cognitive tasks at home, and are often confused and overwhelmed when attempting to operate computers without assistance. We asked if computer-based braining training were made available in a structured training format, at no cost to the participant, would acquired brain injury survivors benefit from using commercially available brain training? Three acquired brain injury patients were recruited. Pre and post training psychometric measures of memory and attention were obtained, as well as qualitative evaluation of the user experience.



Speed Match. This game challenges processing speed and reaction time. It is based on the n-back task. Speed training is designed to improve the ability to think quickly, accurately, and pay attention while others are talking. This screen shot appears courtesy of Lumosity.

Connor, BB, and Shaw, C (2014), Case study series using brain-training games to treat attention and memory following brain injury, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 221–229, Gothenburg, Sweden, 2–4 Sept. 2014.

A serious-gaming alternative to pen-and-paper cognitive scoring – a pilot study

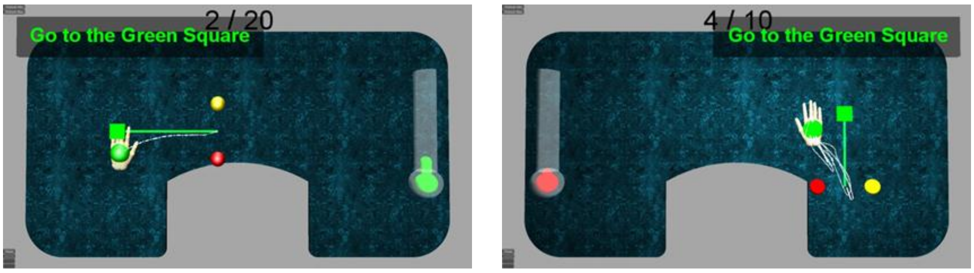
G House, G Burdea, K Polistico, J Ross, M Leibick

1Bright Cloud International Corp, Highland Park, New Jersey, USA

Memory Enhancement Center of America, Inc., Eatontown, New Jersey, USA

ABSTRACT

The majority of cognitive virtual reality (VR) applications have been for therapy, not cognitive stratification/scoring. This paper describes the BrightScreener™ and its first pilot feasibility study for evaluating elderly with various degrees of cognitive impairment. BrightScreener is a portable (laptop-based) serious-gaming system which incorporates a bimanual game interface for more ecological interaction with virtual worlds. A pilot study was undertaken to determine if BrightScreener is able to differentiate levels of cognitive impairment based on game performance, as well as to evaluate the technology acceptance by the target population. 11 elderly subjects were recruited by the Clinical Coordinator at the Memory Enhancement Center of America (MECA, Eatontown, NJ) site. They had an average age of 73.6 years, and averaged 14.5 years of education. Subjects first underwent clinical scoring with the standardised Mini Mental State Exam (MMSE). During the same visit they underwent a familiarization session and then an evaluation session on the BrightScreener. At the end of their visit, each subject filled a subjective evaluation exit form. Technologists were blinded to MMSE scores. Subsequent group analysis of the Pearson correlation coefficient showed a high degree of correlation between the subjects' MMSE scores and their Composite Game Scores (0.90, |P| < 0.01). Despite the small sample size, results suggest that serious-gaming strategies can be used as a digital technique to stratify levels of Cognitive Impairment. This may be an alternative to conventional standardised scoring for Mild Cognitive Impairment and Dementia.



(a) *(b)*

BrightArm training of residents in a dementia ward: (a) subject with intact working memory;(b) subject with no working memory due to Alzheimer's disease (Burdea et al, 2013a). ©Bright Cloud International. Reprinted by permission..

House, G, Burdea, G, Polistico, K, Ross, J, and Leibick, M (2014), A serious-gaming alternative to pen-and-paper cognitive scoring – a pilot study, *Proc. 10th Intl Conf. on Disability*, *Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 231–239, Gothenburg, Sweden, 2–4 Sept. 2014.

Differences in effects when using virtual reality balance trainer or wobble board in terms of postural responses

I Cikajlo, S Bajuk

University Rehabilitation Institute, Ljubljana, SLOVENIA

ABSTRACT

The aim of this study was is twofold: firsts to examine whether the choice of balance training device has any influence on overall therapeutic outcome and secondly whether it affects postural strategy in patients with low-back pain. Six patients used Gamma trainer with virtual reality games and five patients used a wobble board. Before and after the treatment the postural responses were tested. 5 out of 11 patients improved their postural responses in terms of latency and stability. Contribution of the balance training to the improvement of postural responses was not statistically significant (ANOVA, $p > 0.05$), but differences in functional reaching test were statistically significant ($p = 0.0215$) for each group ($p = 0.0419$), while differences between the groups were not found significant ($p = 0.1257$). In spite of small number of participating subjects, we may suggest that balance training improves postural responses and functional reaching in people with low back pain regardless of the choice of the balance training device.

The Gamma device (left) consists of two pressure plates, which monitor the movement of the vertical component of the gravity force. The appropriate information is then displayed in the form of a moving object in a virtual environment.On the wobble board (right) besides balance skills additional muscle strength is required. And in subjects with low-back pain or balance disorders also an assistance of a physiotherapist is mandatory..

Cikajlo, I, and Bajuk, S (2014), Differences in effects when using virtual reality balance trainer or wobble board in terms of postural responses, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 241–247, Gothenburg, Sweden, 2–4 Sept. 2014.

Session IX: Real/Virtual Comparative Studies

Spatial working memory performance in real museum environment versus computer simulation: a comparison between healthy elderly and young adults

M Korman, R Kizony, M Hochhauser, T Kuflik, A J Wecker, P L Weiss

University of Haifa, ISRAEL

Sheba Medical Center, Tel Hashomer, ISRAEL

ABSTRACT

In recognition of the limited ecological validity of testing in a laboratory setting, we compared spatial memory performance of healthy young and older adults in a real museum setting and on a computer simulation. In the museum, participants physically moved between display stations to locate hidden tokens; an ongoing representation of previous searches had to be remembered. A comparable task was implemented via mouse actions on a computer simulation. Nine older (60-80 years) and 20 younger (20-45 years) adults performed both tasks. The younger group was superior to the older group in terms of success and time, and all participants were more efficient within the simulated task. The feasibility of using realistic tasks in a physical location to study spatial memory is discussed.

On-site (museum) setting. Left, Experimental area in the museum, Right, Participant's hand selecting a target while searching for a token.

Korman, M, Kizony, R, Hochhauser, M, Kuflik, T, Wecker, AJ, and Weiss, PL (2014), Spatial working memory performance in real museum environment versus computer simulation: a comparison between healthy elderly and young adults, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 249–255, Gothenburg, Sweden, 2–4 Sept. 2014.

Web accessibility by Morse Code modulated haptics for deaf-blind

L Norberg, T Westin, P Mozelius, M Wiklund

Stockholm University, SWEDEN

ABSTRACT

Providing information using a modality that is both non-visual and non-auditory such as haptic feedback, may be a viable approach regarding web accessibility for deaf-blind. Haptic navigation systems have been shown to be easy to learn (Venesvirta, 2008), and modulating navigation related information as patterns of vibrations has been shown to be perceived as natural and non-intrusive (Szymzcak, Magnusson and Rassmus-Gröhn, 2012). To minimise the bandwidth needed, a varying length encoding scheme such as Morse code may be considered. A prototype Morse code vibration modulated system for web page navigation was developed, using a standard game controller as a means of output. Results show that simulated deaf-blind test subjects using the system were able to navigate a web site successfully in three cases out of four, and that in some situations a version of the system with a higher degree of manual interaction performed better.

Test setup showing use of laptop touch pad for input and Xbox360 controller for output. Test subjects were blindfolded and wore ear protection.

Norberg, L, Westin, T, Mozelius, P, and Wiklund, M (2014), Web accessibility by Morse Code modulated haptics for deaf-blind, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 257–264, Gothenburg, Sweden, 2–4 Sept. 2014.

Intensive language-action therapy in virtual reality for a rehabilitation gaming system

K Grechuta, B Rubio, A Duff, E Duarte Oller, P Verschure

Pompeu Fabra University, Barcelona, SPAIN

Hospital del Mar i l'Esperanza, Barcelona, SPAIN

Institució Catalana de Recerca i Estudis Avançats, Barcelona, SPAIN

ABSTRACT

One third of stroke patients suffer from language disorders. These disorders severely impair individuals' communication abilities, which impacts on their quality of life. Recently, the Intensive Language Action Therapy (ILAT) emerged as a novel paradigm for aphasia rehabilitation. ILAT is grounded in three main principles: intense practice, overcoming the learned non-use, and an individualized training. In the present study we designed and developed a VR based language rehabilitation tool by integrating ILAT's object request LAG in RGS, a novel paradigm for the rehabilitation of motor deficits after lesions to the central nervous system. RGS is a gaming environment that provides a multimodal, task specific training in virtual reality scenarios. Its special design consists of an intelligent motion detection system that monitors the users' movements. This allows for an active interaction as well as continuous evaluation of the affected limbs. We addressed the question whether aphasia rehabilitation designed within the VR environment of RGS can be an effective tool. The principal purpose of the initial pilot study was to validate the system and to learn whether a virtual adaptation of the ILAT into RGS can trigger positive changes in the linguistic behavior of Broca's aphasia patients. We report the results of a double-case initial pilot study where one acute and one chronic aphasic patient followed five RGS-ILAT therapy sessions. Before and after the treatment we evaluated their language skills using the Communication Activity Log (CAL) and Western Aphasia Battery (WAB) scales. Results show that the patients learnt how to interact within the VR system. The CAL performance suggests that both patients and their therapist perceived improvements in the communication skills after the therapy. Additionally, the approval and acceptance of the system were high. Based on this initial outcome we will further provide the present RGS-ILAT with substantive technological advancements and evaluate the system to reliably replicate the original ILAT, in order to better understand the potential of the virtual reality based language rehabilitation therapies.

The virtual scenario of Intensive Language Action Therapy

Grechuta, K, Rubio, B, Duff, A, Duarte Oller, E, and Verschure, P (2014), Intensive language-action therapy in virtual reality for a rehabilitation gaming system, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 265–273, Gothenburg, Sweden, 2–4 Sept. 2014.

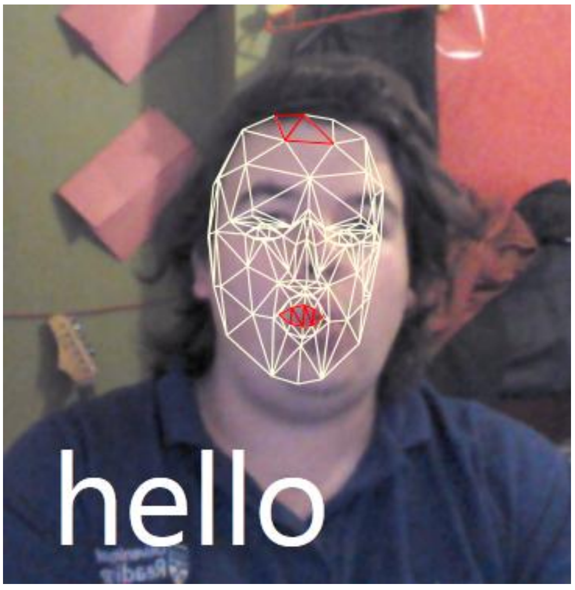
Speech development and therapy using the Kinect

S Frost, R J McCrindle

University of Reading, UK

ABSTRACT

The use of computers and technology to treat patients with developmental problems or rehabilitation needs is an emerging field. Implementation of such treatment methods however has not traditionally been easy, requiring expensive equipment, significant programming experience and the time of trained medical professionals. The release of gaming systems with natural user interfaces has opened up new possibilities for creating home based therapy and rehabilitation systems that are more engaging, affordable and customisable to individual needs. This project leverages the high quality voice and facial recognition capabilities of the Microsoft Kinect natural user interface, and affordable hardware, to provide an interactive speech therapy application that can be used by patients in their own homes, whilst also collecting metric data for remote monitoring by medical professionals to ensure that engagement with, and appropriate progression of, treatment is occurring.



Facial Recognition Map.

Frost, S, and McCrindle, RJ (2014), Speech development and therapy using the Kinect, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 275–284, Gothenburg, Sweden, 2–4 Sept. 2014.

Design and usability evaluation of an audio-based college entrance exam for students with visual disabilities

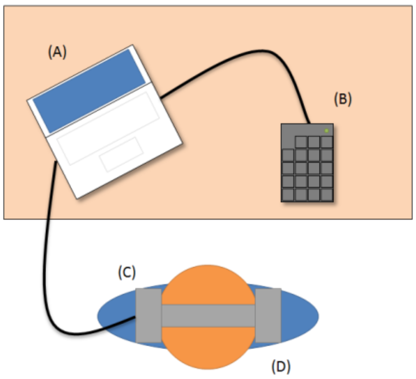
J Sánchez, M Espinoza, M de Borba Campos

University of Chile, Santiago, CHILE

Pontifical Catholic University of Rio Grande do Sul, BRAZIL

ABSTRACT

The purpose of this research was to design, implement and evaluate the usability of a digital pilot system that adapts the Language and Communication subject section of the PSU (Chilean college entry exam), allowing for equal and autonomous participation by learners with visual disabilities in the college selection process. The study was carried out in two stages during the years 2010 and 2012. The pilot project was carried out in December of 2010 in three different regions of Chile, at the same time as the regular process for taking the PSU. Based on the initial results from 2010, the system was redesigned, implemented and evaluated in order to create the final version. The results for the final version of the tool designed demonstrate a high level of usability. This work provides a detailed analysis and discussion of the results obtained in 2012, as well as future directions regarding the issue at hand.



Work station for the AudioPSU user, (A) Netbook, (B) Braille Numpad, (C) Stereo Headphones, (D) User Who is Blind.

Sánchez, J, Espinoza, M, and de Borba Campos, M (2014), Design and usability evaluation of an audio-based college entrance exam for students with visual disabilities, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 285–292, Gothenburg, Sweden, 2–4 Sept. 2014.

Short Papers ~ Abstracts

A participatory design framework for the gamification of rehabilitation systems, **D Charles**, **S McDonough**, University of Ulster, NORTHERN IRELAND

In recent years games and game technology have been used quite widely to investigate if they can help make rehabilitation more engaging for users. The underlying hypothesis is that the motivating qualities of games may be harnessed and embedded into a game-based rehabilitation system to improve the quality of user participation. In this paper we present the PACT framework which has been created to guide the design of gamified rehabilitation systems; placing emphasis on people, aesthetics, context, and technology from the beginning of a design and development process. We discuss the evolution of PACT from our previous GAMER framework, which was used to develop a range of games for upper arm stroke rehabilitation with natural user interfaces. GAMER was established to guide the design of rehabilitation games from the viewpoint of a designer, whereas with PACT greater emphasis has been placed on an inclusive design process. We provide a detailed work flow illustration for the use of PACT in the development of rehabilitation systems and provide examples of practical design and analysis tools that improve the quality of workflow in PACT.

Charles, D, and McDonough, S (2014), A participatory design framework for the gamification of rehabilitation systems, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 293–296, Gothenburg, Sweden, 2–4 Sept. 2014.

Smart cane outdoor navigation system for visually impaired and blind persons, **B Chaudary**, **P Pulli**, University of Oulu, FINLAND

This paper presents prototype of an outdoor navigation system designed to assist visually impaired (VI) and blind persons in outdoor navigation. It assists VI persons in moving independently on sidewalks in urban areas using an augmented guidance cane and informs them about points of interests (POI) through serialized braille encoded vibrational guidance messages. Augmented guidance cane, magnet points' trail, metallic trail, and pulsing magnet apparatus for transmission of serialized braille encoded guidance messages in the form of vibration are the features of the proposed navigation system. Magnet points' trail, metallic trail, and pulsing magnet apparatuses will be installed on the special sidewalks for the visually impaired persons in city centers. VI persons will be able to sense magnet points' trail or metallic trail through augmented guidance cane. It will assist them to walk independently being oriented on the sidewalks. Pulsing magnet apparatuses will be installed at the verge of the POIs on the sidewalks. VI persons will be able to sense the serialized braille vibrational messages through augmented guidance cane and become aware of the POI. Numbers of usability experiments are designed to evaluate the usability of the proposed system in qualitative interviews sessions. It is expected that the results of the qualitative interviews and the test sessions will provide valuable information to make this prototype a full-fledged system ready to be deployed.

Chaudary, B, and Pulli, P (2014), Smart cane outdoor navigation system for visually impaired and blind persons, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 297–300, Gothenburg, Sweden, 2–4 Sept. 2014.

Video-based quantification of patient's compliance, during post-stroke virtual reality rehabilitation, **M Divjak**, **S Zelič**, **A Holobar**, University of Maribor, SLOVENIA

We present a video-based monitoring system for quantification of patient's attention to visual feedback during robot assisted gait rehabilitation. Patient's face and facial features are detected online and used to estimate the approximate gaze direction. This gaze information is then used to calculate various metrics of patient's attention. Results demonstrate that such unobtrusive video-based gaze tracking is feasible and that it can be used to support assessment of patient's compliance with the rehabilitation therapy.

Divjak, M, Zelič, S, and Holobar, A (2014), Video-based quantification of patient's compliance, during post-stroke virtual reality rehabilitation, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 301–304, Gothenburg, Sweden, 2–4 Sept. 2014.

Virtual spatial navigation tests based on animal research – spatial cognition deficit in first episodes of schizophrenia, **I Fajnerová**, **K Vlček**, **C Brom**, **K Dvorská** , **D Levčík**, **L Konrádová**, **P Mikoláš**, **M Ungrmanová**, **M Bída**, **K Blahna**, **F Španiel**, **A Stuchlík**, **J Horáček**, **M Rodriguez**, Prague Psychiatric Center/Institute of Physiology, Academy of Sciences of the Czech Republic/Charles University, CZECH REPUBLIC

The impairment of cognitive functions represents a characteristic manifestation in schizophrenia. Animal models of schizophrenia demonstrated behavioural changes in several spatial tasks. In order to assess spatial abilities in schizophrenia using methods applicable in comparative research, we designed two virtual tasks inspired by animal research: the Morris water maze and the Carousel maze. The tested subject is required to navigate toward several hidden goal positions placed on the floor of an enclosed stable arena or a rotating arena. Data obtained in a group of schizophrenia patients show cognitive impairment in both newly-developed virtual tasks comparing to matched healthy volunteers.

Fajnerová, I, Vlček, K, Brom, C, Dvorská, K, Levčík, D, Konrádová, L, Mikoláš, P, Ungrmanová, M, Bída, M, Blahna, K, Španiel, F, Stuchlík, A, Horáček, J, and Rodriguez, M (2014), Virtual spatial navigation tests based on animal research – spatial cognition deficit in first episodes of schizophrenia, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 305–308, Gothenburg, Sweden, 2–4 Sept. 2014.

Exploring haptic feedback for robot to human communication, **A Ghosh**, **J Penders**, **P Jones**, **H Reed**, **A Sorranzo**, Sheffield Hallam University, Sheffield, UNITED KINGDOM

Search and rescue operations are often undertaken in low-visibility smoky environments in which rescue teams must rely on haptic feedback for navigation and exploration. The overall aim of our research is to enable a human being to explore such environments using a robot. In this paper we focus on creating feedback from a robot to a human. We describe our first designs and trials with vibration motors. The focus is on determining the potential use of vibration motors for message transfer and our trials reflect whether different messages can be discriminated. We describe the testing procedure and the results of our first tests. Based on these results, we conclude that close spatial arrangement of the motors blurs individual signals.

Ghosh, A, Penders, J, Jones, P, Reed, H, and Sorranzo, A (2014), Exploring haptic feedback for robot to human communication, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 309–312, Gothenburg, Sweden, 2–4 Sept. 2014.

Kinecting the moves: the kinematic potential of rehabilitation-specific gaming to inform treatment for hemiplegia, **S M N Glegg**, **C T Hung**, **B A Valdés**, **B D G Kim**, **H F M Van der Loos**, Sunny Hill Health Centre for Children, Vancouver/University of British Columbia, CANADA

Two therapy applications for hemiplegic arm rehabilitation were developed and tested, along with a motion tracking application that used two interfaces (PlayStation® Move and Microsoft® Kinect™) for videogame play through a social media application developed on Facebook©. To promote affected arm use, users are required to employ bimanual symmetrical hand motions. Preliminary kinematic data analysis of two subjects obtained during user testing is presented. Clinically relevant information, such as range of motion, trunk compensation, and total distance of hand movement was extracted from kinematic data. Results showed the system is capable of accommodating users with large variation in arm function.

Glegg, SMN, Hung, CT, Valdés, BA, Kim, BDG, and Van der Loos, HFM (2014), Kinecting the moves: the kinematic potential of rehabilitation-specific gaming to inform treatment for hemiplegia, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 313–316, Gothenburg, Sweden, 2–4 Sept. 2014.

Integrating motor learning and virtual reality into practice: a knowledge translation challenge, **S M N Glegg**, **D E Levac**, **H Sveistrup**, **H Colquhoun**, **H Finestone**, **V DePaul**, **P Miller**, **L Wishart**, **J Harris**, **M Brien**, Sunny Hill Health Centre for Children, Vancouver/University of Ottawa/ Ottawa Hospital Research Institute/Bruyere Continuing Care, Ottawa/ McMaster University/Ottawa Children's Treatment Centre, CANADA

Virtual reality (VR) systems are promising treatment options in stroke rehabilitation because they can incorporate motor learning strategies (MLS) supporting task-oriented practice. A pre-post design was used to evaluate a knowledge translation (KT) strategy supporting therapists in acquiring proficiency with VR while integrating MLS. Following e-learning modules and experiential learning, outcome measures evaluated changes in VR knowledge, attitudes, behaviours and MLS use. Improvements in therapists' behavioural control, self-efficacy, and VR knowledge were observed, though therapists used few MLS, with no improvement over time. Future KT strategies should target proficiency in VR use prior to integration of a theoretical treatment approach.

Glegg, SMN, Levac, DE, Sveistrup, H, Colquhoun, H, Finestone, H, DePaul, V, Miller, P, Wishart, L, Harris, J, and Brien, M (2014), Integrating motor learning and virtual reality into practice: a knowledge translation challenge, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 317–320, Gothenburg, Sweden, 2–4 Sept. 2014.

Assessment of motor function in hemiplegic patients using virtual cycling wheelchair, **R Ishikawa**, **N Sugita**, **M Abe**, **M Yoshizawa**, **K Seki**, **Y Handa**, Tohoku University/Sendai School of Health and Welfare, JAPAN

A cycling wheelchair (CWC) is a rehabilitation tool for hemiplegic patients. In previous studies, our group developed a virtual reality system that allows patients to practice driving a CWC. This study proposes a new method to estimate the torque of each leg extension of a hemiplegic patient while driving the virtual CWC. Experimental results from four healthy subjects and four hemiplegic patients showed the usefulness of the proposed method in evaluating the motor function of the patients.

Ishikawa, R, Sugita, N, Abe, M, Yoshizawa, M, Seki, K, and Handa, Y (2014), Assessment of motor function in hemiplegic patients using virtual cycling wheelchair, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 321–324, Gothenburg, Sweden, 2–4 Sept. 2014.

A comparison of upper limb movement profiles when reaching to virtual and real targets using the Oculus Rift: implications for virtual-reality enhanced stroke rehabilitation, **M A Just**, **P J Stapley**, **M Ros**, **F Naghdy**, **D Stirling**, University of Wollongong, AUSTRALIA

Recent innovations in the field of virtual reality, such as the Oculus Rift head mounted display, provide an unparalleled level of immersion in the virtual world at a cost which is rapidly approaching mainstream availability. Utilising virtual reality has been shown to improve many facets of the rehabilitation process, including patient motivation and participation. These systems, however, do not enable the user to receive feedback when interacting with virtual objects, which may influence the movement profile of a patient. Therefore, to investigate how a virtual environment influences movements during stance, participants were required to reach to a real and a virtual target. Their movements were quantified using a motion capture suit, and the virtual target was generated using the Oculus Rift. The motions to both targets were compared using a number of measures calculated to characterize the velocity profiles.

Just, MA, Stapley, PJ, Ros, M, Naghdy, F, and Stirling, D (2014), A comparison of upper limb movement profiles when reaching to virtual and real targets using the Oculus Rift: implications for virtual-reality enhanced stroke rehabilitation, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 325–328, Gothenburg, Sweden, 2–4 Sept. 2014.

Conducting focus groups in Second Life® on health-related topics, **A Krueger**, **P Colletti**, **H Bogner**, **F Barg**, **M Stineman**, Virtual Ability®, Inc., Aurora, CO/University of Pennsylvania, USA

The “Mrs. A and Mr. B” research project uses focus groups conducted in the virtual world Second Life® to collect qualitative data on healthcare equitability as experienced by persons with and without disabilities. Novel methodological adaptations to traditional focus group methods include avatar consent, text discussion, participant advance preparation and disability accommodation. In this project, focus group findings are used to enrich and clarify results obtained from the analysis of a quantitative administrative dataset derived from Medicare data. In this article, advantages and challenges of using virtual world focus groups are highlighted.

Krueger, A, Colletti, P, Bogner, H, Barg, F, and Stineman, M (2014), Conducting focus groups in Second Life® on health-related topics, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 329–332, Gothenburg, Sweden, 2–4 Sept. 2014.

Physically accurate velocity distribution profiles for use in virtual reality training for prosthetic limbs, **P Kyberd**, **R Bongers**, **S Hamza**, University of New Brunswick, CANADA/University of Groningen, THE NETHERLANDS

Virtual reality has been used in many areas of application, from training to simulation. There is an increasing interest in using VR for training persons for prosthetic limb control. In a prosthesis, a myoelectric signal map to the velocity or position of a prosthetic joint. There is little evidence on what is the appropriate mapping between the myoelectric input and the prosthetic joint output. There is a possibility that a poor mapping will hinder the training. This study is the first stage in the process to understand this mapping, by studying the distribution of velocities in the intact arm in a conventional Fitts law test. What is observed is a wide range of velocities, decreasing in frequency as the velocity increases. This implies that for VR training to be effective a wide range of velocities need to be used in that training.

Kyberd, P, Bongers, R, and Hamza, S (2014), Physically accurate velocity distribution profiles for use in virtual reality training for prosthetic limbs, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 333–336, Gothenburg, Sweden, 2–4 Sept. 2014.

Perception of multi-varied sound patterns of sonified representations of complex systems by people who are blind, **O Lahav**, **J Kittany**, **S T Levy**, **M Furst**, Tel Aviv University/University of Haifa, ISRAEL

Listening to Complexity is a long-term research project, which addresses a central need among people who are blind: providing equal access to the science classroom, by allowing them to explore computer models, independently collect data, adapt and control their learning process. The innovative and low-cost learning system that is used in this project is based on the principle of perceptual compensation via technologies, by harnessing the auditory mode to transmit dynamic and spatial complex information, due to its unique affordances with respect to vision. Sonification of variables and events in an agent-based NetLogo computer model is used to convey information regarding both individual gas particles and system-wide phenomena, using alerts, object and status indicators, data representation and spatial audio displays. The paper describes two experiments: (1) Auditory perception of varying types of auditory representations, spatial trajectories of a modeled object's motion, relative intensity, and frequency; and (2) Auditory perception of complex sound patterns – exploring detection and recognition of multiple sound channels at different complexity levels of sound patterns. The research would serve to improve our understanding of the auditory processes by which perception of sound patterns takes place and transforms into a conceptual model. The long-term practical benefits of this research are likely to have an impact on science, technology, engineering and mathematics education for students who are blind.

Lahav, O, Kittany, J, Levy, ST, and Furst, M (2014), Perception of multi-varied sound patterns of sonified representations of complex systems by people who are blind, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 337–340, Gothenburg, Sweden, 2–4 Sept. 2014.

Adaptation of postural symmetry to an altered visual representation of body position, **M Lemay**, **L-N Veilleux**, **M Marois**, **L Ballaz**, **D M Shiller**, Université du Québec à Montréal/Centre de réadaptation Marie Enfant (CHU Sainte-Justine), Montréal/Université de Montréal, CANADA

The goal of the present study was to determine whether postural symmetry can be altered through sensorimotor adaptation. A gradual change in postural symmetry was induced in participants by biasing visual feedback of their body's center of pressure toward the left or the right. Results showed that this procedure induced a significant shift in participants' stance, which resulted in postural asymmetry and altered postural control that persisted beyond the period of altered visual feedback. We discuss the implications of such visuo-motor procedures for the rehabilitation of patients with postural asymmetry.

Lemay, M, Veilleux, L-N, Marois, M, Ballaz, L, and Shiller, DM (2014), Adaptation of postural symmetry to an altered visual representation of body position, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 341–344, Gothenburg, Sweden, 2–4 Sept. 2014.

Virtual anatomical interactivity: developing a future rehabilitation aid for survivors of Acquired Brain Injury, **V Macri**, **P Zilber**, **V J Macri**, 3D PreMotorSkills Technology, Durham, New Hampshire, USA

Anatomically realistic virtual upper extremities with analogous true range of motion were developed and made available in a platform of video game-like exercises and tasks to pilot test re-learning to plan and execute purposeful motor control and related executive function in survivors of acquired brain injury. The platform game-play is designed for survivors disabled from using physical extremities due to brain injury and for other conditions of brain-motor malfunction. Survivors control virtual upper extremities (before being able to control physical extremities), in order to simulate on-screen physical exercises and task completions, i.e. they stimulate brain processes for pre-action planning and training. This paper describes several imagery (visualization) methods of virtual reality rehabilitation, reports on use of a virtual anatomical interactivity ("VAI") platform by twelve participant/survivors of acquired brain injury and suggests opportunities for expanded collaborative research.

Macri, V, Zilber, P, and Macri, VJ (2014), Virtual anatomical interactivity: developing a future rehabilitation aid for survivors of Acquired Brain Injury, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 345–348, Gothenburg, Sweden, 2–4 Sept. 2014.

Enhancing brain activity by controlling virtual objects with the eye, **C Modroño**, **J Plata**, **E Hernández**, **I Galván**, **S García**, **F Zelaya**, **F Marcano**, **O Casanova**, **G Navarrete**, **M Mas**, **J L González-Mora**, University of La Laguna/Hospital Universitario de Canarias, Tenerife, SPAIN/King's College London, UK/Diego Portales University, CHILE

Stimulation of the damaged neural networks is a key factor for the reorganization of neural functions in the treatment of motor deficits. This work explores, using functional MRI, a system to activate motor regions that does not require voluntary limb movements. Healthy participants, in a virtual environment, controlled a virtual paddle using only their eye movements, which was related with an increase of the activity in frontoparietal motor regions. This may be a promising way to enhance motor activity without resorting to limb movements that are not always possible in patients with motor deficits.

Modroño, C, Plata, J, Hernández, E, Galván, I, García, S, Zelaya, F, Marcano, F, Casanova, O, Navarrete, G, Mas, M, and González-Mora, JL (2014), Enhancing brain activity by controlling virtual objects with the eye, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 349–352, Gothenburg, Sweden, 2–4 Sept. 2014.

Minimally invasive, maximally effective: multisensory meditation environments promote wellbeing, **H J Moller**, **L Saynor**, **H Bal**, **K Sudan**, University of Toronto/University of Waterloo/OCAD University/Praxis Holistic Health, Toronto, CANADA

Increasing evidence is pointing towards the health benefits of leisure: freely chosen, intrinsically motivated and self-directed "flow states", often environment-directed and quite probably with the potential to enact potent changes of consciousness. Optimal leisure experiences are thought to result in enhanced mental wellbeing, positive affect and transformational learning states that carry over into effectively coping with daily routines, stresses and roles. Our group has developed and researched the medically supervised administration of standardized simulated leisure-state meditation experiences in the context of pleasant, hedonic sensory input incorporating multiple sensory channels (visual, auditory, haptic) to promote broad-spectrum wellbeing in mental health care. In this brief report, we report on clinical outcomes for a case series of patients undertaking a therapeutic protocol of TEMM- a technology-enhanced multimodal meditation stress-reduction program with a broad-spectrum mental health benefit, analogous to conventional Mindfulness Based Stress Reduction (MBSR) programs, and a therapeutic risk-benefit margin possibly superior and often preferred by patients to medication therapy attending a holistic health centre. We touch upon seamless diagnostic evaluation and clinical utility of Wellpad, our Electronic Medical Record (EMR) system developed using an iterative Inclusive Design approach. We place our multisensory meditation therapy within the scope of Virtual Environment Therapy (VET) and suggest the mechanism of action as an induced leisure or flow state to potentiate relaxation, stress-reduction, resilience and personal transformation. The relevance of leisure states to wellbeing and specifically positive experiential learning through inspirational/motivational shifts in consciousness delivered via multimodal immersive environments are described as an important health promotion avenue to pursue and the VET research community to consider.

Moller, HJ, Saynor, L, Bal, H, and Sudan, K (2014), Minimally invasive, maximally effective: multisensory meditation environments promote wellbeing, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 353–356, Gothenburg, Sweden, 2–4 Sept. 2014.

Raised-dot slippage perception on fingerpad using active wheel device, **Y Nomura**, **H Kato**, Mie University, JAPAN

To improve the slippage perceptual characteristics with the fingertip cutaneous sensation, we have introduced raised dots on the surface of a wheel rotating on an index fingerpad. Examining the perceptual characteristics of the raised-dot slippages by psychophysical experiments, we obtained factor effects on the perception. As a result of ANOVA, it was confirmed there was a significant difference among the three surfaces: the 3.2 mm period of raised dots, the 12.8 mm periods of raised dots, and the without-raised-dots smooth surface.

Nomura, Y, and Kato, H (2014), Raised-dot slippage perception on fingerpad using active wheel device, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 357–360, Gothenburg, Sweden, 2–4 Sept. 2014.

Low-cost active video game console development for dynamic postural control training, **A Pouliot-Laforte**, **E Auvinet**, **M Lemay**, **L Ballaz**, Université du Québec à Montréal/UHC Sainte-Justine Research Center, Montreal/École Polytechnique de Montréal/Quebec Rehabilitation Research Network, Montreal, CANADA

Weight shifting is a key ability to train and monitor in rehabilitation processes. In the last decade, active video game console (AVGC) has been viewed as a promising and appealing way to solicitate weight shifting ability. However, to date, no commercially available AVGC was specifically developed for balance and postural control throughout rehabilitation processes. The present study aims to establish a proof of concept about the possibility to integrate, in a unique AVGC, a board, monitoring the player centre of pressure and a Kinect, which take into account the postural movement and the player motor function capacity.

Pouliot-Laforte, A, Auvinet, E, Lemay, M, and Ballaz, L (2014), Low-cost active video game console development for dynamic postural control training, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 361–364, Gothenburg, Sweden, 2–4 Sept. 2014.

Evidence-based facial design of an interactive virtual advocate, **W A Powell**, **T A Garner**, **D Tonks**, **T Lee**, University of Portsmouth/University of Kent, UK

RITA (Responsive InTeractive Advocate) is the vision for a computer software-based advocacy and companion service to support older adults and provide an alternative to institutional care. The RITA service will offer a preventative care approach, creating a digital champion who will learn an individual's needs and preferences over time, and be a friendly interface between users, family and professionals. This will involve the integration of a variety of technical components: (1) The Face - a realistic and emotionally expressive avatar, encouraging communication and interaction; (2) The Mind - a repository to store, organise and interpret personal and memory-related information representing the "essence" of a person, with user-defined access controls; (3) The Heart - an empathetic sensory interface which is able to understand and respond to the physical, emotional and psychological needs of the user. Each of these aspects presents a series of technical challenges, which will be addressed by combining existing state-of-the art techniques from a variety of disciplines, together with innovative processes and algorithms, to improve and extend functionality. RITA is being designed in consultation with user groups and service providers, and drawing extensively on existing research to inform the design and functionality of the system. In this short paper we introduce the design and development of the face of RITA.

Powell, WA, Garner, TA, Tonks, D, and Lee, T (2014), Evidence-based facial design of an interactive virtual advocate, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 365–368, Gothenburg, Sweden, 2–4 Sept. 2014.

Study of geometric dispatching of four-kinect tracking module inside a Cave, **S Salous**, **T Ridene**, **J Newton**, **S Chendeb**, Paris 8 University, FRANCE

In a virtual reality application that requires the user to interact with his environment and in the context of an application inside a virtual reality room (CAVE) there is an ever increasing need to optimize the interaction cycle in all its steps, especially in the tracking step. Many existent tracking systems are used inside CAVEs, in this paper we propose a study of geometric dispatching of four-kinects inside a CAVE to be used as a tracking module for virtual reality applications.

Salous, S, Ridene, T, Newton, J, and Chendeb, S (2014), Study of geometric dispatching of four-kinect tracking module inside a Cave, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 369–372, Gothenburg, Sweden, 2–4 Sept. 2014.

Harnessing the experience of presence for virtual motor rehabilitation: towards a guideline for the development of virtual reality environments, **T Schüler**, **L Ferreira dos Santos**, **S Hoermann**, University of Osnabrück/Technische Universität Berlin, GERMANY/University of Otago, NEW ZEALAND

The experience of presence has been shown to be important for virtual motor rehabilitation. Despite its importance, current research and therapy systems often make only limited use of it. This article introduces a conceptualization of presence that provides a guideline for the implementation of virtual rehabilitation environments. Three types of visual feedback in virtual rehabilitation systems are linked to three dimensions of presence. In particular it is shown how movement visualization, performance feedback and context information correspond to the presence dimensions: spatial presence, involvement and realness. In addition, practical implications are discussed to support the development of future virtual rehabilitation systems and to allow better use of the experience of presence for virtual motor rehabilitation after stroke.

Schüler, T, Ferreira dos Santos, L, and Hoermann, S (2014), Harnessing the experience of presence for virtual motor rehabilitation: towards a guideline for the development of virtual reality environments, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 373–376, Gothenburg, Sweden, 2–4 Sept. 2014.

The potentiality of virtual reality for the evaluation of spatial abilities: the mental spatial reference frame test, **S Serino**, **F Morganti**, **P Cipresso**, **E E R Magni**, **G Riva**, IRCCS Istituto Auxologico Italiano, Milan/University of Bergamo/Università Cattolica del Sacro Cuore, ITALY

In recent decades, the use of Virtual Reality (VR) in the context of cognitive evaluation of dementia has considerably increased. The main objective of this preliminary study is to assess the feasibility of a VR-based tool for detecting deficits in using different spatial reference frames by comparing the performances of patients with probable Alzheimer's Disease (AD) with cognitively healthy controls. Although preliminary, our results showed the potentiality of using this VR-based tool to evaluate the ability in encoding and using different spatial reference frames.

Serino, S, Morganti, F, Cipresso, P, Magni, EER, and Riva, G (2014), The potentiality of virtual reality for the evaluation of spatial abilities: the mental spatial reference frame test, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 377–380, Gothenburg, Sweden, 2–4 Sept. 2014.

Improved mobility and reduced fall risk in older adults after five weeks of virtual reality training, **S R Shema**, **P Bezalel**, **Z Sberlo**, **O Wachsler Yannai**, **N Giladi**, **J M Hausdorff**, **A Mirelman**, Tel Aviv Sourasky Medical Center/Tel-Aviv University, ISRAEL/Harvard Medical School, Boston, USA

The aim of this analysis was to assess whether 5 weeks of training with virtual reality (VR) in a clinical setting can reduce the risk of falls in a variety of older adults. Thirty-four participants attending the VR clinic were studied. Participants underwent 15 training sessions consisting of walking on a treadmill with a VR simulation. Significant improvements were observed in gait speed, the Four Square Step Test and the Timed Up and Go. Treadmill training with VR appears to be an effective and practical clinical tool to improve mobility and reduce fall risk in older adults.

Shema, SR, Bezalel, P, Sberlo, Z, Wachsler Yannai, O, Giladi, N, Hausdorff, JM, and Mirelman, A (2014), Improved mobility and reduced fall risk in older adults after five weeks of virtual reality training, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 381–384, Gothenburg, Sweden, 2–4 Sept. 2014.

Realistic and adaptive cognitive training using virtual characters, **D Sjölie**, University of Gothenburg, SWEDEN

Computer-aided cognitive training has the potential to be an important tool in the fight against dementia and cognitive decline but many challenges remain. This paper presents an example of how realistic and adaptive training may address these challenges. Virtual characters were used as stimuli in a dual n-back working memory task in a realistic 3d-environment. Support for continuous adaptation was a priority, including adaption based on affective states such as arousal.

Sjölie, D (2014), Realistic and adaptive cognitive training using virtual characters, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 385–388, Gothenburg, Sweden, 2–4 Sept. 2014.

Performance analysis of adults with Acquired Brain Injury making errands in a virtual supermarket, **E Sorita**, **P A Joseph**, **B N'Kaoua**, **J Ruiz**, **A Simion**, **J M Mazaux**, **E Klinger**, Université de Bordeaux/CHU Bordeaux/ESIEA, Laval, FRANCE

Virtual Environments (VE) offer the opportunity to analyze the performance of people with Acquired Brain Injury (ABI) in Instrumental Activities of Daily Living (IADL). A number of studies have been carried out with the Virtual Action Planning Supermarket (VAP-S) among adult populations with cognitive disorders. Dysexecutive components such as planning have been identified from VAP-S outcome measures. The aim of this study is to explore the links between patients' performance, daily life integration and data from neuropsychological tests.50 adults with ABI in chronic stage (mean delay post onset = 54 ± 53 months) were recruited from a social and work integration program. A Principal Component Analysis (PCA) including a neuropsychological battery, the community integration questionnaire (CIQ) and performance in the VAP-S.The PCA raises four factors that explain 70% of the total variance. These factors show that the performance in the VAP-S cannot be only explained by executive functioning but dynamically mix high and low cognitive processes. Interesting questions also raise to know if performance in the VAP-S would only reflect cognitive disorders or conversely an adaptation level from preserved capacities. Functional performance in VAP-S virtual environment offers promising information on the impact of neuropsychological diseases in daily life. Executive functions impairment is showed. However other cognitive components are involved in VAP-S performance.

Sorita, E, Joseph, PA, N'Kaoua, B, Ruiz, J, Simion, A, Mazaux, JM, and Klinger, E (2014), Performance analysis of adults with Acquired Brain Injury making errands in a virtual supermarket, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 389–392, Gothenburg, Sweden, 2–4 Sept. 2014.

Color-check in stroke rehabilitation games, **V Szücs**, **C Sik Lanyi**, **F Szabo**, **P Csuti**, University of Pannonia, HUNGARY

The article presents the colorimetric testing of rehabilitation games designed for the StrokeBack project. In this testing the main subject of the investigation was how the people with different colour-blindness types can percept the games. Many of the programmers and game designers do not pay attention to the aspect that the games should be accessible. This accessibility implies that the colour-blind users should be able to use the games the same way as the people with no vision problems.

Szücs, V, Sik Lanyi, C, Szabo, F, and Csuti, P (2014), Color-check in stroke rehabilitation games, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 393–396, Gothenburg, Sweden, 2–4 Sept. 2014.

Challenges in developing new technologies for special needs education: a force-field analysis, **P L Weiss**, **S V G Cobb**, **M Zancanaro**, University of Haifa, ISRAEL/ University of Nottingham, UK/3FBK – Fondazione Bruno Kessler, ITALY

Introduction of new technologies for use in special needs education requires careful design to ensure that their use is suitable for the intended users in the context of use and that learners benefit from the experience. This paper discusses issues that influence implementation of collaborative technologies designed to support learning of social communication skills in young people with autism. Taking a reflective view of lessons learned during the COSPATIAL project, a force-field analysis was applied to identify positive factors contributing to successful application development and negative factors that disrupted progress and implementation of the software. On the basis of our experience in the COSPATIAL project, recommendations for future projects are made.

Weiss, PL, Cobb, SVG, and Zancanaro, M (2014), Challenges in developing new technologies for special needs education: a force-field analysis, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 397–400, Gothenburg, Sweden, 2–4 Sept. 2014.

Self-management intervention for amputees in a virtual world environment, **S L Winkler**, **R Cooper**, **K Kraiger**, **A Ludwig**, **A Krueger**, **I Gaunaurd**, **A Fisher**, **J Kairalla**, **S Elliott**, **S Wilson**, **A Esquenazi**, Nova Southeastern University/Miami Department of Veterans Affairs Medical Center/Nova Southeastern University/Colorado State University/Virtual Ability, Inc. Aurora, CO/US Army Telemedicine & Advanced Technology Research Center (TATRC), Fort Detrick, MD/University of Florida/Elliott e-learning Solutions, Chicago/MossRehab Einstein Healthcare Network, Philadelphia, USA

An e-learning self-management intervention for amputees was created then beta-tested for usability using focus groups and qualitative analyses. The next phase of the study compares change in outcomes when the intervention is presented in e-learning and virtual world conditions. Focus group results identified the self-directed structure and video presentation aspects of the intervention as strengths and were less enthusiastic about use of text. Research team experiences, beta test results, and available technology suggest the need to rethink traditional learning theory in order to meet the needs of the modern learner and create more modern learning environments.

Winkler, SL, Cooper, R, Kraiger, K, Ludwig, A, Krueger, A, Gaunaurd, I, Fisher, A, Kairalla, J, Elliott, S, Wilson, S, and Esquenazi, A (2014), Self-management intervention for amputees in a virtual world environment, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 401–404, Gothenburg, Sweden, 2–4 Sept. 2014.

Grid-pattern indicating interface for ambient assisted living, **G Yamamoto**, **Z Asghar**, **Y Uranishi**, **T Taketomi**, **C Sandor**, **T Kuroda**, **P Pulli**, **H Kato**, Nara Institute of Science Technology/University Hospital, Kyoto University, JAPAN/University of Oulu, FINLAND

We propose a grid-pattern indicating interface to provide instructions remotely from remote site to support independent daily life of senior citizens. Our aim is to realize smooth and easy telecommunication between supported senior citizens at local site and supporting caregivers who are in remote site. Although we have used a monitoring method with video streaming where the remote caregivers indicate work steps as a conventional way, occlusion and depth perception problem was occurred. Our method that provides grid-pattern interface to remote caregivers could be a solution for the problems by indicating the spatial instruction easily on 2D input interface. Our prototype has been implemented with a colour camera, a range image sensor, and projector.

Yamamoto, G, Asghar, Z, Uranishi, Y, Taketomi, T, Sandor, C, Kuroda, T, Pulli, P, and Kato, H (2014), Grid-pattern indicating interface for ambient assisted living, *Proc. 10th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, PM Sharkey, L Pareto, J Broeren, M Rydmark (Eds), pp. 405–408, Gothenburg, Sweden, 2–4 Sept. 2014.

Development of a real world simulation to study cognitive, locomotor and metabolic processes in older adults

R Kizony[1,2], G Zeilig[3,4], P L Weiss[2], I Baum-Cohen[2], Y Bahat[1],
E Kodesh[5], M Bondi[3], I Mintz[6], M Kafri[5]

[1]Center of Advanced Technologies in Rehabilitation
Sheba Medical Center, Tel Hashomer, ISRAEL

[2]Department of Occupational Therapy
University of Haifa, Haifa, ISRAEL

[3]Department of Neurological Rehabilitation
Sheba Medical Center, Tel Hashomer, ISRAEL

[4]Sackler Faculty of Medicine
Tel Aviv University, Tel Aviv, ISRAEL

[5]Department of Physical Therapy
University of Haifa, Haifa, ISRAEL

[5]Department of Physical Therapy
Sheba Medical Center, Tel-Hashomer, ISRAEL

rkizony@univ.haifa.ac.il,yotam.bahat@gmail.com,tamar@research.haifa.ac.il, ilanit.nit@gmail.com, Gabi.Zeilig@sheba.health.gov.il, Moshe.Bondi@sheba.health.gov.il, mkafri@univ.haifa.ac.il, ekodesh@univ.haifa.ac.il, igormintz@gmail.com

ABSTRACT

The purpose of this paper was to demonstrate a proof of concept concerning the design and implementation of a simulation that replicates a real world environment in order to evaluate a complex task of shopping within a mall while measuring cognitive, motor and metabolic aspects of the task. The paper presents the experimental protocol and results from four young healthy and two elderly adults who performed the Multiple Errands Test in both simulated and real world settings. These initial findings show the feasibility of the protocol in both environments.

1. INTRODUCTION

Increased life expectancies now enable people to live 20 to 25% of their lives in retirement. They wish and are expected to maintain a more active life style. Nine out of 10 seniors continue to live in their own homes. However, the ability to accomplish what has become known as “successful aging” demands certain accommodations to support and compensate for declining functional abilities (Bowling, 2007). Universal design embodies the concept of designing all products and environments to be usable by and supportive to the greatest extent possible of everyone, regardless of age, ability, or status (Buiza et al, 2009). Despite such lofty ideals, aging is associated with increased physical and cognitive disability that lead to considerable daily challenges in social participation and/or the full accomplishment of life habits including every day, basic or instrumental activities such as shopping. Fricke & Unsworth (2001) found that 90.9% of older participants spent half their day on tasks related to Instrumental Activities of Daily living (IADL); they perceived the most important IADL to be transportation (walking as well as driving). Food shopping is also a necessary daily activity which contributes to a person’s sense of independence (Thompson et al, 2011).

Although research of older age has grown substantially, not enough is known about how older adults perform in complex life situations; this is partially due to technical limitations of measurement tools. Mitchell (http://livinglabs.mit.edu/) proposed the concept of “Living Labs as a research paradigm for sensing, prototyping, validating and refining complex solutions in multiple and evolving real life contexts”. The Living Lab aims to provide the definitive realization of participatory design to identify true behaviour (Følstad, 2008).

One of the goals of a “Living Lab” is to assess behaviour in complex settings and to find ways to overcome environmental barriers as in the strategic interdisciplinary and multi-sectorial research study that is exploring the principal obstacles, either physical or psychosocial, to social participation and inclusion for persons with disabilities in a commercial mall environment (www.crir-livinglabvivant.com). Simulation of these complex settings enables analysis of performance with greater accuracy as well as evaluation of various solutions before their implementation in a real environment. Simulations running on a range of virtual reality (VR) platforms enable objective and accurate measurement of behaviour in challenging, ecologically-valid and safe environments, while controlling delivery of stimulus and maintaining standardization of measurement protocols (Rizzo & Kim, 2005). Over the years many functional virtual environments (VEs) were developed in order to measure or train skills needed for daily activities (e.g., Kizony et al. 2010; Klinger et al, 2004; Rand et al, 2005; Fung et al, 2006). Research has shown transfer of these skills to real world settings (e.g., Stanton et al, 2002; Rand et al, 2009a; 2009b).

Recently, simulations of almost identical replications of real world environments (e.g., a shopping mall or a house) were created to assess clients' cognitive-functional skills (Koenig et al, 2011; Koenig, 2012; Sangani et al, 2012; 2013). However, most VEs do not enable the replication of task complexity in the real world, i.e., walking at a self-selected speed while stopping to perform a task such as buying an item and then continuing to walk. Rather, measurement in most VEs is restricted to isolated motor or cognitive aspects of task performance. Recent literature suggests that the use of assessment strategies that focus on body function and/or activity (i.e., isolated tasks) rather than on participation (i.e., complex functional tasks) do not sufficiently take into account all of the factors that contribute to or detract from successful functioning (Burgess et al, 2006) and especially do not account for age-dependent decline. In addition, most studies have examined the contribution of isolated factors (e.g., cognition or metabolism) to participation, which limits a full understanding of performance in complex life situation. Whether decline in function due to aging is viewed as a disease or whether it is viewed as a natural process, it is important to understand and characterize the ways in which age-related impairment of cognitive, motor and physiological processes, individually or in combination, impede the ability of elderly persons to accomplish daily tasks in complex life situations. This may only be accomplished via a multi-dimensional approach to experimental design and data collection.

The objectives of this paper are to (1) describe the process of creating and implementing a realistic simulation of an actual complex environment that can be navigated and used to perform functional tasks; (2) describe the functional tasks created within this simulation and the outcomes used to monitor the metabolic, locomotion and cognitive aspects of the task; (3) show proof of concept by comparing performance of a small number of healthy young adults in the simulation to their performance in the real world, as a first step prior to the testing of older adults.

2. METHODS

2.1 Simulation and real world shopping malls

A simulation of a small shopping mall located at the Sheba Medical Center (Tel Hashomer, Israel) was created. The first stage before building the simulation was to sketch the mall structure and take photographs of the stores within it. Additional photographs were taken inside some of the stores (e.g., shelves, items for sale) to enable the creation of functional tasks within these stores. The VE was created with XSI (Autodesk®) using two main techniques: (1) Inserting the photographs onto a 2D grid (x and y axes) in order to create 2D objects that produce the illusion of 3D spaces (see Figures 1and 2). (2) A skeleton of the mall (corridors, floors, ceiling, tables) and items in several stores and kiosks (e.g., lottery tickets, magazines) were created as 3D objects. The 3D objects were wrapped by textures from the photographs taken in the real mall. The participants were able to interact with, i.e., "buy" these items.

The simulation runs in the CAREN™ (Computer Assisted Rehabilitation Environment) Integrated Reality System using DFlow software (www.e-motek.com) and is projected onto a 52" wall-mounted monitor. The participant walked on an interactive, self-paced instrumented treadmill (VGait; Motek Medical B.V.) facing the monitor and navigated through the simulation with a joystick (see Figure 3). The scene is shown to advance in accordance with the speed of the treadmill, i.e., the participant's self-paced speed of gait. In addition, 20 passive markers were placed on the participant's anatomical landmarks and sampled at 120 Hz to record 3D trunk and limb motion. The markers were detected by an optokinetic system which consists of 12 VICON infra-red cameras having a resolution of 2 megapixels (www.vicon.com). The markers were detected by CAREN to activate the self-paced treadmill and to enable interaction with the 3D objects. Data from the simulation, treadmill and markers were recorded and synchronized via CAREN.

Figure 1. A *screen shot of simulated clothing store (left) and a photo of the actual store (right) in the Sheba Medical Center shopping mall.*

Figure 2. A *screen shot of simulated fast food restaurant (left) and a photo of the actual fast food restaurant (right) in the Sheba Medical Center shopping mall.*

Figure 3. A *screen shot of the simulation's set up at the Center of Advanced Technologies in Rehabilitation, Sheba Medical Center, Tel Hashomer, Israel*.

The real mall is a small shopping area of about 12 stores all located on the same floor of a building at the Sheba Medical Center. The mall contains stores that sell clothing, books, handbags as well as a coffee shop, a fast-food outlet, a lottery and other kiosks and a bank.

2.2 Experimental tasks and apparatus

The Multiple Errands Test-Simplified Version (MET-SV or MET) (Alderman et al, 2003) was designed to examine Executive Functions (EF) in a real mall environment. The participant was asked to perform three types of tasks in the shopping mall: purchase six items, obtain and record four pieces of information, and meet the examiner at a preset location and time while abiding by certain rules. The examiner observed the participant, recording strategies and mistakes. The MET-SV has been validated on a variety of populations (Dawson, 2005; Revach & Katz, 2005). The Virtual MET (VMET) (Rand et al, 2009a) is an adapted version of the MET. It consists of the same number of tasks but the products have been changed to those that may be found in the simulated mall. In both MET and VMET, lower scores represent better performance. Metabolic and gait parameters were measured while performing the MET and the VMET.

Metabolic measures included oxygen consumption (VO_2) and respiratory frequency (RF) as markers for energy expenditure and respiratory function and were measured using the $K4b^2$ system, a portable transmitting unit affixed to a chest harness and a receiving unit. The $K4b^2$ has been shown to be an accurate method of assessing VO_2 and RF over a wide range of exercise intensities (McLaughlin et al, 2001). Heart rate (HR) was measured with a Polar heart rate monitor strapped around the chest.

The Mobility lab System (http://www.apdm.com/gait-and-posture/Mobility-Lab/) was used to measure gait variables (e.g., speed, stride time and length, cadence) during the MET and VMET. It consists of six small wireless OPAL^{TM} movement monitors that are affixed to the participant's hands, legs and waist. The monitors do not interfere with walking. It has been shown to be sensitive and reliable (Salarian et al, 2010).

The Six-Minute Walk test (6MWT) (Montgomery & Gardner, 1998); participants were asked to walk in their self-selected comfortable speed for a 6 minute period.

Perceived exertion was measured by Borg's scale, rated from 6 (minimal effort) to 20 (maximal effort). Validity of the scale has been established by the demonstration of correlations between the rate of perceived exertion (RPE) and heart rate, %VO2 max (Carvalho et al, 2009).

The Short Feedback Questionnaire (SFQ) (Kizony et al, 2006) is based, in part, on a translated version of Witmer and Singer's Presence Questionnaire (1998) and was administered after the participants experienced the VMET. These six items query participant's (1) feeling of enjoyment, (2) sense of being in environment, (3) success, (4) control, (5) perception of the environment as being realistic and (6) whether the feedback from the computer was understandable. An additional question was added to inquire whether the participants felt any discomfort during the experience.

2.3 Procedure

Participants were tested during two 120-minute sessions, separated by up to three weeks. Data were collected in two locations at the Sheba Medical Center (Tel Hashomer, Israel); the MET was performed at the Medical Center's shopping mall and the VMET was performed at the Center of Advanced Technologies in Rehabilitation. During the first session, baseline metabolic measures were obtained while the participant sat quietly (15 min) and then during the 6MWT at a self-selected comfortable pace. Thereafter, the participant performed the MET in the real mall or the VMET in the simulation. Before the VMET was performed, a 10 minute training period in the simulation was given to familiarize participants with the setting, interaction and walking on a self-paced treadmill. After completion of the VMET, each participant was asked to rate the SFQ items. While performing the MET and VMET tasks, O2 consumption, CO2 production and heart rate were monitored. During the second session, a baseline of metabolic measures was obtained as described above.

3. RESULTS

3.1 Feasibility of protocol

To date, four healthy young adults (2 male, 2 female; aged 20.5, 21, 25 and 29 years) and two older adults (male; aged; 83 and 69.5), cognitively intact (Mini-Mental State Exam equal to 29 and 30 respectively) completed the full protocol.

The young adults and the 69 year old male were able to perform the task and testing protocols in both the real and simulated environments while data were collected via the gait and metabolic systems. The 83 year old male was able to complete the practice tasks within the simulation but encountered difficulties when trying to perform the multitasking. In addition the protocol was not completed due to technical issues. Due to technical issues with the measurement tools gait variables from the APDM system were not recorded for participants 1 and 2 in the real world, and metabolic variables were not collected for participant 1 in the real world.

3.2 Performance of the MET and VMET

Results from the MET and VMET are presented in Table 1. Time to complete the task was the same or shorter in the simulation. However, 4/6 participants performed worse in the simulation.

Table 1. *Performance (time and scores) of the MET and VMET. Lower scores on the MET and VMET represent better performance. N/A indicates that data are not available.*

			Time to complete (min)		**Total Score**	
Participant	Age (years)	Gender	MET	VMET	MET	VMET
1	21.0	male	19.0	15.4	3	6
2	29.0	female	17.0	17.0	6	2
3	25.0	male	22.15	15.0	0	8
4	20.5	female	11.3	12.32	3	5
5	83.0	male	29.38	N/A	5	10
6	69.5	male	24.33	18	1	1

Table 2. *Gait speed and metabolic outcomes for each participant during three conditions. Mean and (standard deviations) are shown when applicable. N/A indicates that data are not available. Data are presented as means (standard deviation).*

Participant	**Variable**	**Comfortable speed**	**MET**	**VMET**
1	Gait Speed (m/s)	1.04 (0.11)	N/A	0.6 (0.1)
	Metabolic equivalents	3.3 (0.7)	N/A	2.3 (0.8)
	HR (b/min.)	99 (3.8)	N/A	94 (3.7)
	RF (b/min.)	21.4 (3.2)	N/A	17.5 (3.8)
	Borg's Scale	N/A	6	11
2	Gait Speed (m/s)	1.5 (0.08)	N/A	0.7 (0.3)
	Metabolic equivalents	3.57 (0.9)	2.32 (1)	2.12 (0.8)
	HR (b/min.)	105.2 (1.5)	103.5 (5.1)	100.3 (3.1)
	RF (b/min.)	26.3 (4.9)	27 (6.4)	26.7 (6.9)
	Borg's Scale	N/A	10	11
3	Gait Speed (m/s)	1.5 (0.09)	1.1 (0.07)	0.7 (0.1)
	Metabolic equivalents	3.0 (1.3)	2.2 (0.8)	2.8 (1)
	HR (b/min.)	115 (3.5)	123.8 (6.7)	115.4 (5.5)
	RF (b/min.)	26.6 (13.3)	24.9 (9.3)	23.5 (4.5)
	Borg's Scale	N/A	9	12
4	Gait Speed (m/s)	1.7 (0.1)	1.3 (0.1)	0.7 (0.1)
	Metabolic equivalents	4.19 (0.3)	2.3 (0.6)	1.5 (0.27)
	HR (b/min.)	124 (4.6)	108 (10.5)	78 (3.4)
	RF (b/min.)	40.7 (1.7)	37.5 (3.4)	29 (2.4)
	Borg's Scale	N/A	11	11
5	Gait Speed (m/s)	1.2 (0.8)	0.9 (0.05)	0.7 (0.07)
	Metabolic equivalents	2.9 (0.2)	1.6 (0.4)	N/A
	HR (b/min.)	84 (0.9)	89 (2.6)	N/A
	RF (b/min.)	15.7 (0.8)	16.7 (3.3)	N/A
	Borg's Scale	N/A	11	15
6	Gait Speed (m/s)	1.5 (0.09)	1.3 (0.09)	0.5 (0.2)
	Metabolic equivalents	2.7 (0.2)	1.6 (0.6)	1.6 (0.3)
	HR (b/min.)	92 (1.9)	91 (7.0)	76 (6.0)
	RF (b/min.)	23.1 (2.2)	24 (2.7)	22.8 (2.3)
	Borg's Scale	N/A	7	9

3.3 Metabolic measurements

Mean values of metabolic equivalents, heart rate (HR) and RF of the participants as well as their gait speed are presented in Table 2. Data from the last four minutes of the 6MWT (comfortable speed) and during the time while shopping in the simulated mall and in the real world have been analyzed to date. Metabolic equivalents were calculated by dividing the mean VO_2 during the activity by 3.5 (which is a generic value of resting oxygen consumption). Intensity of physical activity is classified based on the metabolic equivalents with metabolic equivalents lower than 3 (indicating light intensity), between 3 and 6 (representing moderate intensity), and higher than 6 (representing vigorous intensity) (ACSM's guidelines, 2009). Metabolic equivalent values indicate that performing the shopping task either in the simulation or the real world involved activity at light intensity across the participants tested so far. The perceived exertion as measured by Borg's scale supports the metabolic measurements indicating activity at light intensity, except for the 83 year old participant who rated his exertion during the activity in the simulation as hard (Carvalho et al, 2009). Intensity of comfortable walking in comparison with the activities in either the simulation or real world was slightly higher and reached the lower end of moderate intensity in the young participants and the higher end of the range of light intensity in the older participants. HR and RF values did not present consistent pattern.

3.4 Locomotion measurements

Gait outcomes that are sensitive to changes in cognitive load and task complexity are presented in Tables 2 and 3. Means and SDs of gait speed (Table 2) and cadence (Table 3) as well as number of strides, coefficient of variance (CoV) of stride length and stride time (Table 3) are presented. The gait parameters represent data that was cleaned from turns and stops that were done due to the nature of the task. Gait speed decreased from 6MWT to MET and was the slowest during the VMET. In most cases, this was accompanied by and an increase in CoV of stride length and time with the largest CoV shown during the VMET. Distance walked within the simulation ranged between 100 and 286 meters.

3.5 Short feedback questionnaire

Participants enjoyed the experience in the simulation (scores of 4.5/5 for the younger participants and 3/5 for the older participants) but they all reported that it was only moderately realistic (scores varying between 3/5-4/5). Five participants stated that the feedback for their actions was very clear (5 out of 5). No cybersickness-type side effects were reported by the participants.

4. CONCLUSIONS

The main purpose of this paper was to demonstrate a proof of concept of the design and implementation of a simulation and the real world environment that it replicates. Both enabled evaluation of the complex task of shopping within a mall while measuring motor, cognitive and metabolic variables. This was accomplished by testing four healthy young adults and two healthy older adults, as a step before the recruitment of older adults with Minimal Cognitive Impairment. The results demonstrated the feasibility of the protocol during both the simulated and the real world tasks. We were able to collect the metabolic and cardiopulmonary as well as locomotion data in both environments even though the collection of metabolic data requires the wearing of a mask. The disturbance to the participant's ability to communicate and field of view due to the mask did not appear to unduly constrain performance during either the MET or VMET tasks.

The measurement of performance during realistic activities is often difficult to achieve due to issues related to encumbrance, ecological validity and valid monitoring. Previous attempts to accomplish this goal usually involved simpler experimental paradigms and, hence, more limited data outcomes. For example, tasks described in the literature were performed either while standing (e.g., Rand et al, 2009a) or walking through one aisle without stopping to shop as would normally occur in the real world (e.g., Kizony et al, 2010). In contrast, the simulation developed for the current study supports the participant's need to engage in multi-tasking activities, such as walking at their comfortable speed and stopping to "shop" for items in accordance with the task's demands.

For the four young and one older participants tested so far, the MET and the VMET were easy to perform, from both physical and cognitive aspects, as reflected by the total scores of the tests and the metabolic outcomes. The oldest participant (83 years) had more difficulties during the VMET and whether it was due to aging or due to technological issues should be further examined. The estimated metabolic equivalents reported in the compendium of physical activities for this type of activity (i.e., food shopping) are 2.3 (Ainsworth et al, 2000) which is similar to the metabolic equivalents calculated for our participants in both environments. This indicates that the demands of the tasks used in our protocol appear to be similar to real world shopping tasks.

The simulation described in this paper appears to have considerable potential to assess behaviours similar to those seen in the real world but at a higher resolution which may provide results that will be useful in designing a "living lab" in the future. However, differences in gait parameters and their influence on performance should be further examined. We believe that these combined metabolic, gait and cognitive data will help to explore the strategies used by participants to accomplish functional tasks such as shopping.

Table 3. *Gait outcomes during the three conditions (Comfortable speed, MET, VMET). Mean and (standard deviations) are shown when applicable. N/A indicates that data are not available.* Cov = coefficient of variance

Participant		**Comfortable speed**	**MET**	**VMET**
1	Number of strides	170	N/A	128
	Stride Length (Cov)	0.09	N/A	0.3
	Stride time (Cov)	0.08	N/A	0.13
	Cadence (steps/min)	85.5 (13.3)	N/A	77.3 (12.5)
2	Number of strides	322	N/A	289
	Stride Length (Cov)	0.04	N/A	0.2
	Stride time (Cov)	0.03	N/A	0.3
	Cadence (steps/min)	114.2 (3.3)	N/A	73 (0.2)
3	Number of strides	313	229	330
	Stride Length (Cov)	0.04	0.09	0.2
	Stride time (Cov)	0.03	0.06	0.09
	Cadence (steps/min)	113.5 (6.8)	116.5 (10.8)	92.1 (9.5)
4	Number of strides	357	168	63
	Stride Length (Cov)	0.04	0.12	0.17
	Stride time (Cov)	0.03	0.08	0.1
	Cadence (steps/min)	124.7 (4.0)	113.6 (10.8)	69.7 (7.8)
5	Number of strides	287	158	88
	Stride Length (Cov)	0.05	0.16	0.14
	Stride time (Cov)	0.03	0.08	0.07
	Cadence (steps/min)	103.2 (3.7)	107.3 (10.1)	99.2 (11.8)
6	Number of strides	321	266	193
	Stride Length (Cov)	0.04	0.09	0.3
	Stride time (Cov)	0.07	0.06	0.2
	Cadence (steps/min)	114.1 (4.6)	106.3 (6.9)	81.1 (0.2)

Acknowledgements: This study was supported by the Israel Science Foundation (Grant No. 942/12).

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Computerised help information and interaction project for people with memory loss and mild dementia

S Jawaid, R J McCrindle

School of Systems Engineering, University of Reading,
Whiteknights, Reading, UK

s.jawaid@student.reading.ac.uk, *r.j.mccrindle@reading.ac.uk*

www.rdg.ac.uk/sse

ABSTRACT

People have to perform many tasks and remember many different things during the course of their daily lives. Remembering them all is a challenge for everyone and especially so if a person has age associated memory impairment or some form of dementia. As technologies such as RFID (Radio Frequency Identification) and Near Field Communication (NFC) tags become more cheaply available and more seamlessly integrated into our lives as the Internet of Things (IoT), it makes sense to use these technologies to help people remember information or automate tasks. The CHIIP (Computerised Help Information and Interaction Project) project has created a framework that uses smartphones and sensor technologies to help people perform tasks that are relevant or specific to them quickly and efficiently within their homes or local environment.

1. INTRODUCTION

People perform many tasks each day as part of everyday living. Such tasks might be done at the same time on a daily basis, for example cooking a meal or taking medicine; regularly, such as switching off the iron, or closing windows before going out; or sporadically, such as remembering to send a birthday card to a friend or attend a meeting. It is natural for someone to forget to do, or worry that they have forgotten to do, some things some of the time, particularly if they have busy lives requiring many different and often varied tasks to be done. As people become older they also find that it becomes harder to remember things. This age-associated memory impairment, is a common problem in people over the age of 60, and is not dementia. Dementia, is an umbrella term for the symptoms that occur when the brain is damaged by diseases, such as Alzheimer’s disease or stroke resulting in a progressive loss of mental ability and symptoms that may include problems with memory, understanding, judgement, thinking and language (Alzheimer’s Society, 2014; Patient, 2014).

The number of people with dementia is steadily increasing. There are currently 800,000 people in the UK, and 35.6 million people worldwide with a form of dementia, figures that are expected to double every 20 years such that by 2050 it is projected that there will be 115.4 million people with dementia worldwide. Established prevalence rates for dementia in the UK are 1 in 1400 at 40-64 years; 1 in 100 at 65-69 years; 1 on 25 at 70-79 years and 1 in 6 at 80+ years (Alzheimer’s Society, 2013). Worldwide, the total number of new cases of dementia each year is 7.7 million, equating to one new case every 4 seconds. Not only is dementia a quality of life issue, there is also a huge economic cost associated with the disease of US$ 604 billion per year, and an overwhelming requirement for carers and caregiving (Carers Trust, 2014); all factors recognised in the 2012 report by the World Health Organization which declared dementia as a global health challenge (World Health Organisation, 2012).

People live for many years after the onset of symptoms of dementia and with appropriate support, many can maintain a good quality of life and continue to engage and contribute within society (World Health Organization, 2012). Whilst technology can never replace the value of personal care it can help support a person as they grow older and can be useful for helping them maintain their independence, at least in the early stages, should they develop dementia or experience other memory related problems.

As mobile and sensor technologies mature and converge to become the internet-of-things (IoT) (Technology Strategy Board, 2014), and as people become more accustomed to using smartphones, it seems appropriate to use these technologies to create an app, that can remind people of what tasks need to be undertaken and where possible to assist or automate the undertaking of them.

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This paper describes a mobile app, CHIIP (Computerised Help Information and Interaction Project), that works in conjunction with small low cost, low powered sensors that can be placed around a person's home and local environment to provide a ubiquitous and personalized aide to everyday living for people as they age.

2. INTERACTION TECHNOLOGIES

2.1 Internet of Things

The project builds upon the concept of the Internet of Things (IoT) whereby objects and people are provided with unique identifiers such that automatic transfer of data and communication can occur between them without the need for human intervention (WhatIs.com, 2014; IERC, 2012). At the point of definition, RFID (Radio Frequency Identification) was seen as the pre-requisite technology for the IoT (Lahtela, 2009), with the vision that if all objects and people were equipped with identifiers, it would transform their daily lives and the way in which they completed day to day actions (Magrassi et al 2001; Casaleggio Association, 2011).

Subsequently, the list of enabling technologies for creating an IoT has been extended with RFID, barcodes, QR-codes and digital watermarking all able to achieve tagging of items. Another recent technology is NFC (Near Field Communication), an enhancement of the RFID concept, which involves small tags with a chip inside them that can hold small amounts of data. These tags can cause actions to be executed when interaction occurs with an NFC enabled device, such as a smartphone or NFC reader. This technology is now being used in systems such as the contact-less payment systems provided by Google Wallet and Barclaycard platform (BusinessWire, 2012).

With technologies such as NFC tags becoming more cheaply available and a large proportion of smartphones and other devices becoming compatible with these technologies, it makes sense to start using them to automate tasks, or assist people with what they need to know, as they go about their everyday lives.

2.2 Interaction Technologies

The CHIIP project has created a framework that uses mobile phones and sensor technologies to help people perform tasks that are relevant or specific to them quickly and efficiently and in doing so help them to manage busy lives, or to remember how to do things should their memory start to become impaired through age related memory loss or the onset of dementia. The project considered the pros and cons of different sensor related technologies (see Table 1) before selecting NFC technology due to its low cost and accessibility through Android support.

Table 1. *Hardware for Sensor Interaction.*

Hardware Type	Description	Positives	Negatives
Raspberry PI	A credit-card sized computer capable of computer processing similar to a desktop PC	• Many home automation possibilities	• Price • Less mobile
RFID (Radio Frequency Identification)	A wireless contact-less use of radio-frequency electromagnetic fields to transfer data. Available in a variety of types such as tags	• Covers wide distance for interaction • Uses radio waves	• Older technology • Needs additional hardware for scanning
Digital Watermarking	A way of adding digital information to media and other printed material.	• Imperceptible to humans • Easily detected by computers	• Imperceptible to humans • Not easy to do at home
QR-Codes (Quick Response Codes)	A type of two-dimensional barcode that can be read by smartphones and dedicated QR reading devices such as scanners	• Cheap to create • Easy to produce at home via printer	• Difficult to customise • Difficult to produce (print) • Easily tampered with
NFC (Near Field Communication)	A wireless communication technology that allows transferring of data between 2 devices (such as a mobile phone and an NFC Tag)	• Low price • Variety of tags • Android support • Low power	• Close distance for interaction • Memory size restrictions

2.3 NFC (Near Field Communication)

NFC (Near Field Communication) is a wireless communication that allows transfer of data between two devices, such as a mobile phone and an NFC Tag (RapidNFC, 2014). This transfer takes place when an NFC enabled device comes into close proximity of an NFC tag, replacing Bluetooth technology. It can also be extended to perform certain actions based on the data held on the phone such as linking to a website for marketing purposes, flight check-ins at airports, retail item stock checking and even contactless payments between mobile phones and payment terminals. NFC tags come in a variety of formats, for example stickers, wristbands and key-rings such as those shown in Figure 1. These tags contain a small microchip with a little aerial that can store small amounts of data dependent on the memory capacity of the tag (KimTag, 2014). These data are usually stored in NDEF (NFC data exchange format) format, which is a standard and allows the data to be reliably read by most NFC enabled devices.

Figure 1. *NFC Tags* [RapidNFC, 2014].

2.4 Use of NFC (Near Field Communication)

Another advantage of NFC is the number of management tools now available to assist with the development of applications that can exploit NFC technology either by allowing the app developer to see details of tags (such as size, type and state of the tag) or by providing functionality that allow tags to be configured and written to task lists which are completed upon scanning the tag. Some of the most popular tools available are NFCTagWriter-NXP, NFCTagStore, Samsung TecTiles, with the most commonly used being NFC TagLauncher (Trigger) by Egomotion Corp with over 1 million + downloads (EgoMotion Corp, 2014). However, although NFC TagLauncher is a highly useful application that allows users to very easily setup a tag to complete a certain set of actions upon scanning an NFC tag, it only allows a tag to be used for one set of tasks. This can be a disadvantage for home scenarios as a tag placed in a common room can only be used by one users set of instructions at a time.

Table 2. *Hardware for Sensor Interaction.*

Application Name	Description	Positives	Limitations
NFC Tag Launcher (Trigger)	Tag tasks configuration	Easy to use interface. Large task list & Tasker integration Supports multiple task triggers (NFC, Wifi, Geo-fencing)	One task set per tag
NFC TagWriter by NXP	Tag management	Simple interface Detailed tag description	Amount of tasks available One task per tag
NFC Actions	Tag tasks configuration	Simple interface	One task set per tag Task list
NFC TagStore	Task management	Simple interface Good suggestions of task uses	Limited amount of task functionality
NFC TagInfo	Tag management	Detailed description of tag components	No task selection (only tag data visibility)
Send! File Transfer (NFC)	NFC file sender	Simple interface Quick to setup	No task selection (only sending of files using NFC)
NFC Passport Reader	NFC Passport RFID reader	Simple interface	Limited to application passport scenario
AnyTAG NFC Launcher	Tag tasks configuration	Very simple interface Tasker integration	Advertisements Limited task list One task set per tag
NFC Doctor	Tag management	Simple functionality	No task selection (only tag data visibility)
NFC Launcher	NFC marketing campaign management	Cloud based Login authentication	Limited to application marketing scenario
Microsoft Tag, QR, NFC	Tag scanner	Useful for poster and NFC touch points History of NFC tags scanned Good looking interface	Only makes use of already configured NFC tags and touch points
Samsung TecTiles	Tag tasks configuration	Large task list Uses modes such as (Home Mode, Car Mode)	Recommended for TecTiles tags Interface not easy to use Limited to 3 modes (Home, Car and office).

2.5 Reminder Systems

An important function of the CHIIP project is to act as a reminder system for tasks that people need to undertake or activities related to tasks they have done, for example, people may need to be reminded to take their medicine at a particular time of the day, or asked whether they have switched of the gas after making a meal. In order to help ascertain requirements a number of current reminder systems were reviewed in order to see what features they provide and how they automate cues to complete certain actions including Tamkang University RFID Reminder System (Hsu, 2011) and the LLC Wellness Wizard Voice Reminder System (LLC, 2014).

As a result of reviewing these reminder systems, the following requirements emerged as being important: (1) Making it easy to add reminders. (2) Making use of the user's calendars and alarm clock to manage and present reminders. (3) Using voice, device, SMS and email based reminders for different reminder types, such as voice based reminders to a person when leaving and entering the house and SMS messages to inform friends or family that a person has left or returned home.

2.6 NFC Use in Healthcare Projects

NFC is starting to be used in relation to the healthcare industry and for ambient assisted living (Iglesias et al, 2009; Dohr et al, 2010; Menschner et al, 2011). Some applications, for example, NFC Patient Wristband – (Taiwan Mobile, 2014) and the Homecare Project (Pique, 2013) are being used by healthcare professionals to help manage patient care, whilst others such as the Dementia House (Stirling University, 2012) and FotoDialer (2014) are being used by patients themselves. There appears to be few applications however that assist people to live independently by reminding them of, and/or automating, the numerous different tasks they undertake throughout the entire day, via one integrated application. This is the primary aim of the CHIIP system.

3. COMPUTERISED HELP AND INFORMATION PROJECT (CHIIP)

CHIIP is designed to help in various situations around the home and outside of it, and to be used by many different demographics of people including children, students, parents and busy professionals, but with its greatest potential being to support people as they grow older and experience problems with their memory. The CHIIP project has developed a system consisting of an Android phone app and NFC tags that can be easily set up and personalised by a person, their carer or a health professional in order that a range of support reminders and tasks can be specified that are relevant to an individuals' preferences and activities. For example, it can remind an elderly person to take their medicine, enable them to send emergency messages, or give them instructions of how to make a simple meal. A tag could even be placed in their friend's house for mobile reminders and to tell family members or other carers that they have arrived safely at their intended venue.

3.1 Framework

The range of tasks that can be brought into the CHIIP system is potentially limitless and is extensible. The app provides an easy to use interface and a framework whereby tasks can be added or changed based on user demand or as a person's needs, activity patterns or level of required support change. Reminders and tasks can be specified by anyone, such as an older person's family member or carer as long as they know how to use a smartphone. The older person themselves need then only remember the one simple action of putting their mobile phone close to a tag to initiate a reminder or action. This can be aided using specifically coloured NFC Tags or custom tags with photos of their carer, activity or object in order to aid the recognition process.

3.2 Functionality

Technically the project extends the functionality provided by applications such as NFC TagLauncher, which allow users to quickly configure tags to complete actions, by enabling a single tag to be used by multiple users. This is particularly useful in a home scenario where a tag could be placed in each room of the house. This allows different users within a family, or a husband and wife, to use a single tag for custom purposes, for example a tag placed near the front door could be used by parents to remind them that they need to close the windows before leaving the house, by the children to remind them that they need to have their sports kit for school, and by a grandparent to remind them to take their key or to send an automatic message to someone telling them that they have left the house. If an older person is still able to drive but has problems remembering how to use the phone or satellite navigation system in a car then a single NFC tag sticker can be placed inside a car phone dock that will automatically turn the phone on loud, turn on Bluetooth, open navigation and send a message to say that they are in the car – just by placing their phone near the tag on the dashboard thereby simplifying a potentially complex set of processes into one single step. The system could also be used to open a person's favourite website, remind them to take their medicine, give instructions for how to make a cup of tea, call emergency services, or turn lights on and off if connected to a home automation system.

4. DEVELOPMENT

The application has been developed using an Android smartphone and NFC tags. The phone stores login details via the Android `SharedPreferences` which allows persistent key-value pairs to be saved and retrieved. `SharedPreferences` are also used to save the custom data for each tag task, for example a task to open a website, requires the website URL to be saved. Storage and retrieval of tag task selection information is provided by an SQLite database. SQLite is included in every Android device, and does not require specific setup.

The application follows a tab style experience that allows the user to setup a tag which then needs to be scanned to complete the allocated tasks. Upon scanning a tag, the application reads the tag name, checks what tasks are assigned to it using the database, and calls the relevant functionality. Each task when executing checks its type and gets extra information from `SharedPreferences`, such as the fact that it is a voice reminder task with custom message text.

Using the tag reference as the lookup value means that many users can use the same tag to perform a different set of tasks personalised to their needs or activities. The storage of this data is very small and so a large number of tags (placed in various locations around the home and local environment) can be programmed and stored in the application to automate everyday tasks.

The application has been designed using recommendations from the Google Developer website (2014) and the inclusion of multiple themes along with a font size changer, make it easily usable and accessible for a large number of users. Figure 2 shows the overall architecture of the system and Figure 3 the flow of activity through the system.

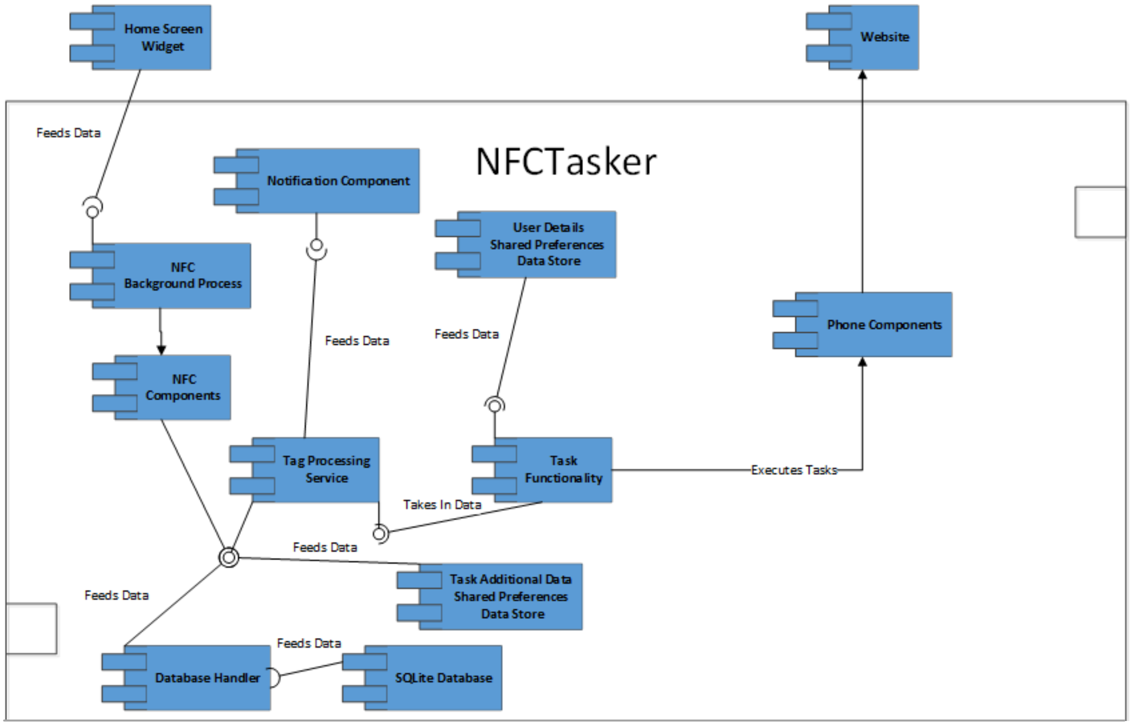

Figure 2. *High level overview of system components of CHIPP system (NFCTasker).*

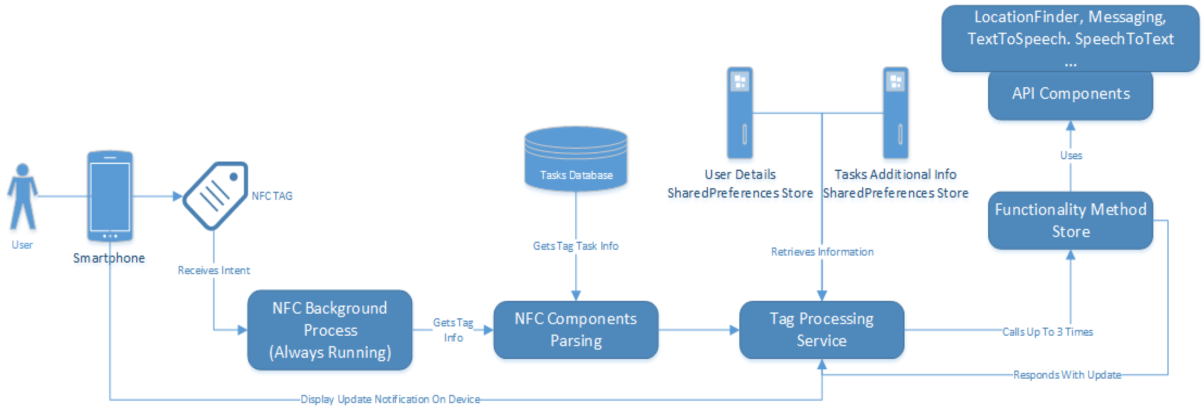

Figure 3. Tag *process flow and data retrieval.*

5. RESULTS - CHIIP USE TO SUPPORT PEOPLE WITH DEMENTIA

The CHIIP system comprises three key components: (1) a smartphone, (2) NFC tags and (3) a software app that is downloaded to the smartphone that acts as an initiator for the interaction and responses. NFC tags can be placed in different locations inside or outside of the home (Figure 4), in a car and on personal items such as key rings. These tags can be given a reference name which can then be assigned tasks in the smartphone application. The user then interacts with the tags by placing their smartphone near them – initiating the actions that the user previously set. Example interactions might include:

- NFC sticker placed near the front door: *Voice reminder to remind about a task when leaving/entering the house. *Recorded voice playback of a reminder message.
- NFC sticker placed in car: *Enable Bluetooth for Bluetooth headset, *switch phone to loud mode, *open maps navigation.
- NFC key-ring / wristband emergency tag: *Send location emergency message to a carer, *call ambulance services.

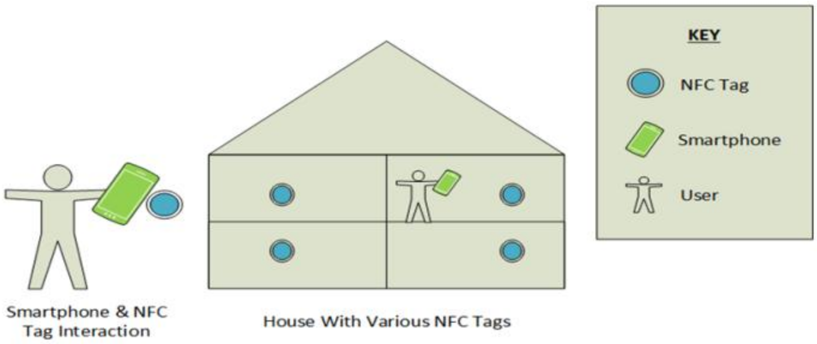

Figure 4. *Home with NFC Tags.*

As well as setting actions to tags, the application allows two types of voice reminders to be set, one using a built in voice library and the other using sound files recorded by the carer, which is particularly useful to aid recognition for the patient as shown in Figure 5.

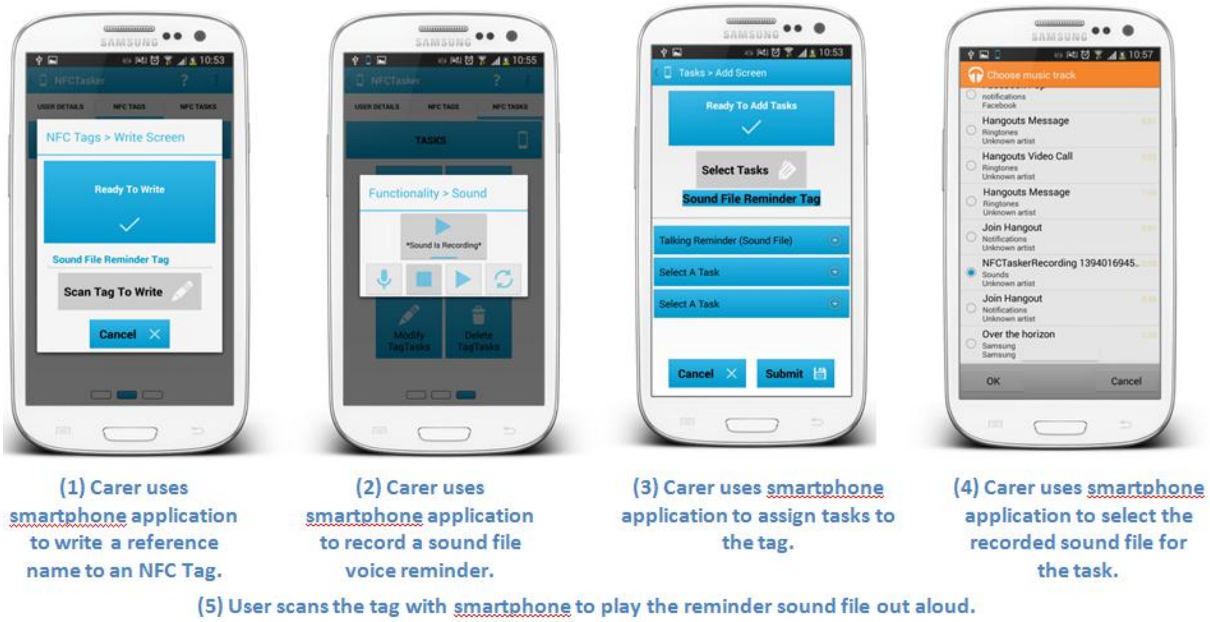

Figure 5. *Phone setup to enable information or actions to be associated with tags.*

A carer could write/record tags to remind a person to take their medication as shown in Figures 6 and 7.

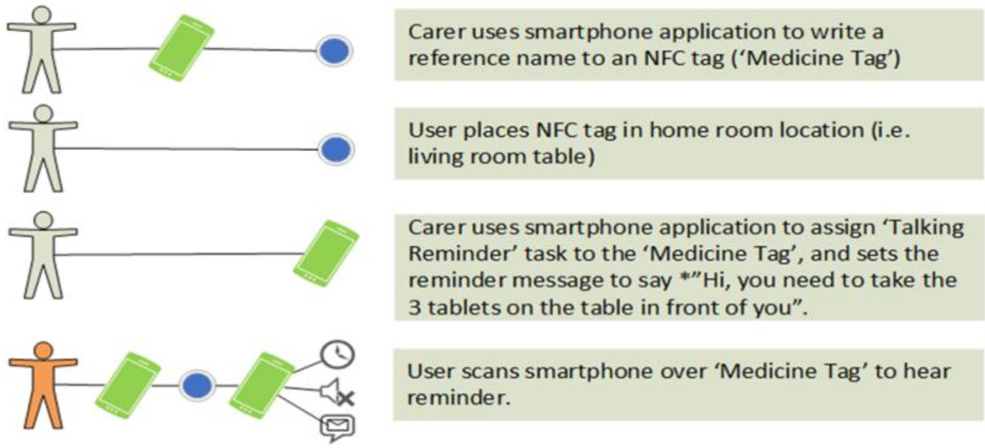

Figure 6. *Carer assigns a medicine reminder tag.*

CHIIP is a complete and fully functional application that can be used by anyone who has an Android smartphone. Tags can be written for any number of information cues, reminders or actions utilising a wide range of NFC tags which can be worn on or carried by a person, positioned within their homes, or in their local environments. The application has been demonstrated to 10 elderly people who were asked to rate the usefulness of various tasks, to suggest further tasks and to give their opinions on the usefulness of the application with results given in Figure 8.

Showcasing of the technology to clinical experts in stroke and dementia has also taken place at an Aphasia Workshop and to members of the public at a Café Scientifique and a University Open Day. The system has been very well received during these demonstrations with resultant useful feedback and ideas for further tasks that would be useful to incorporate in the system for people with mild dementia or memory loss. The technology has been successfully trialed in home environments and more formal trials in the homes of people with early stages of dementia are being discussed. Ways to make the system more widely available are also being considered.

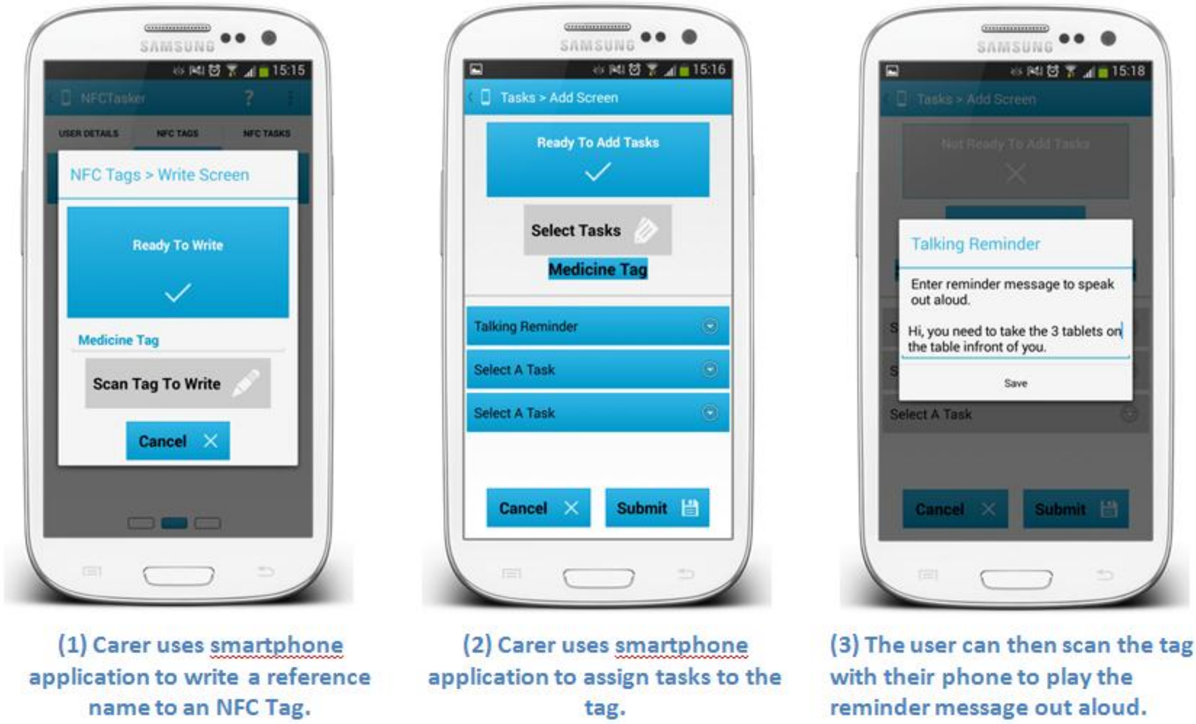

Figure 7. *Phone setup to assign the medicine tag.*

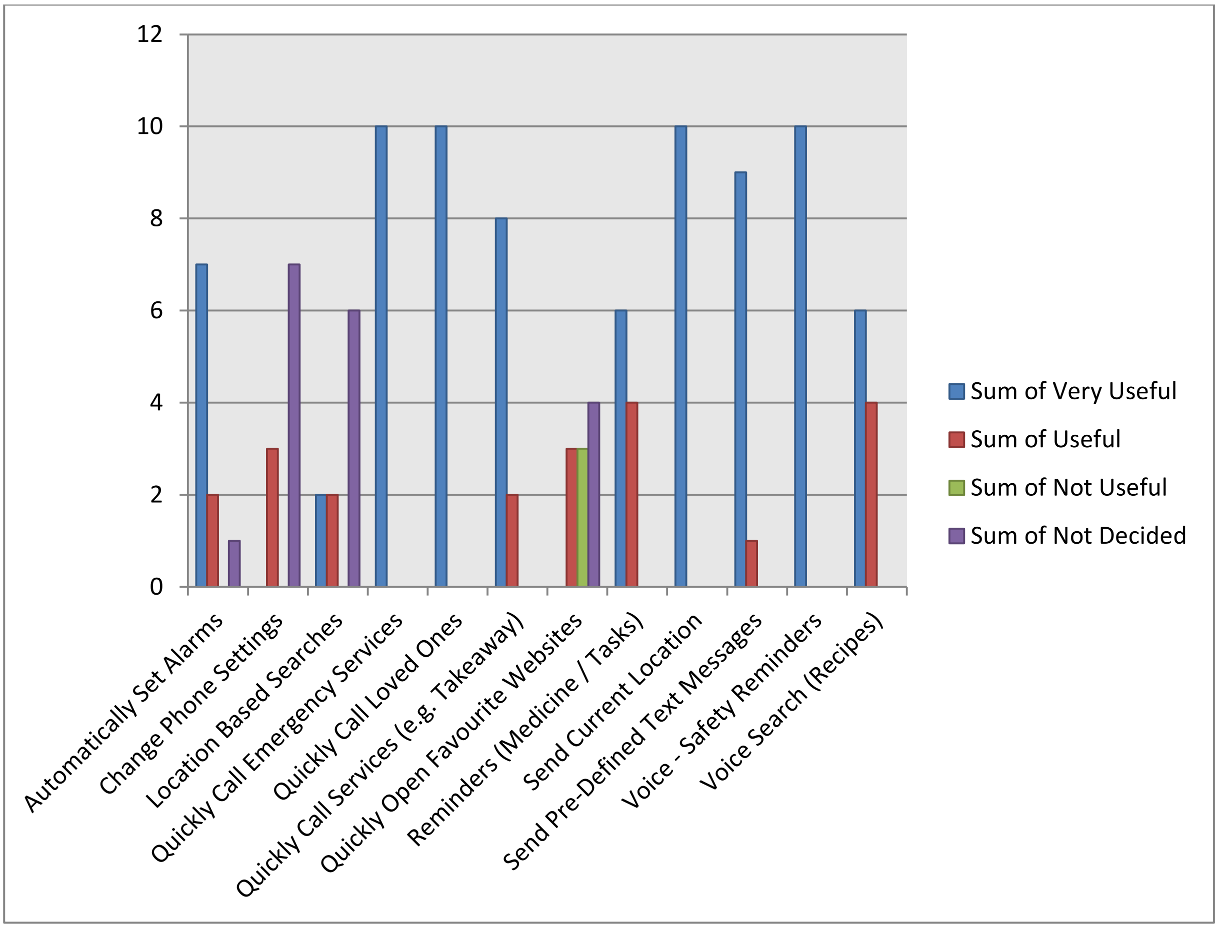

Figure 8. *Chart showing responses for elderly user group questionnaire tasks.*

5. CONCLUSIONS AND FURTHER WORK

As populations age, the number of people experiencing age related memory decline and dementia increases necessitating increased care and support especially if people are to remain living independently in their own homes for as long as possible. Whilst technology can never be a complete substitute for human contact, it can help and support older people to live safer and more independent lives and give greater peace of mind to those caring for them especially when they are not cohabiting with the person they are caring for. Provision of assistance to people with memory loss or dementia and those who care for them has high individual and societal impacts in terms of safety, security, independence and quality of life.

The CHIIP project addresses some of the stresses and issues related to age related memory loss or mild dementia by providing the ability to set personalised reminders and actions based on a person's needs and lifestyle. These may include, for example, reminders to take medicines, close windows, check the iron is switched off, make a cup of tea etc. The application can also include location based tasks for people who are more mobile including finding a nearby place to eat, directions to a nearby petrol station, and messaging family members when they leave or return home. The key benefits of CHIIP are (1) it is affordable, especially if a person already owns a smartphone; (2) the app can be downloaded and installed within seconds and can be set up for use within minutes by anyone with a small knowledge of how to use a smart phone; (3) it only requires the older user to remember the single action of holding the phone close to a tag in order to be reminded of something or to perform an action; (4) through the NFCTasker functionality of CHIIP, the same tag can be associated with a number of tasks and hence used by different people for responses or actions personalised to them.

Following the evaluations that took place between April and June, a number of extended trials are being planned in the homes of individuals with mild dementia or age related memory loss in conjunction with social care providers. Discussions are also underway as to how to make the system available more widely. The system is also being extended with tags for other user groups including school children, students, working professionals, and individuals with special educational or work needs. Closer linkage of the system to home automation systems is also being investigated. Porting the application to other phones is under consideration; however, whilst most developers have included NFC in their recent phones, Apple has yet to commit, to NFC technology (NFC World, 2014), although it is rumoured that NFC technology will be included in the iPhone 6 (Mac Rumours, 2014).

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Usability assessment of natural user interfaces during serious games: adjustments for dementia intervention

V Vallejo[1], I Tarnanas[1], T Yamaguchi[2], T Tsukagoshi[2], R Yasuda[2], R Müri[1,3], U P Mosimann[1,4], T Nef[1]

[1]ARTORG Center, Gerontechnology and Rehabilitation Group, University of Bern, Murtenstrasse 50, Bern, SWITZERLAND

[2]Department of Applied Electronics, Tokyo University of Science, 6-3-1, Niijuku, Katsushika-ku, Tokyo, JAPAN

[3]Perception and Eye Movement Laboratory, Department of Neurology and Clinical Research, University Hospital, Inselspital, Bern, SWITZERLAND

[4]Department of Old Age Psychiatry, University Hospital of Psychiatry, Inselspital, Bern, SWITZERLAND

{vanessa.vallejo, ioannis.tarnanas, tobias.nef}@artorg.unibe.ch, tk-ymgch@te.noda.tus.ac.jp, rene.mueri@insel.ch, urs.mosimann@gef.be.ch

ABSTRACT

Serious games based rehabilitation program needs a comprehensive and people-centred design for a better efficacy. In most studies benchmarking the computer-interaction interfaces is a prerequisite for adjusting the most appropriate user input for the rehabilitation application. The present study examines a comparison between three natural user interfaces and two standard computer interfaces in two different virtual reality tasks. The results illustrate that the acceptance and user-friendliness of a device regarding the completion of a specific task strongly depends on the task itself and on the abilities of the users.

1. INTRODUCTION

Over the last decade, the field of virtual reality has been applied in various domains such as education, medicine, psychology and has been adapted to various target populations. The older adults are a common target for virtual reality technologies, since a virtual environment can be utilized for addressing some of the situations that they encounter in real life (Sawyerr and Pinkwart, 2011). For example, Morganti, Stefanini and Riva (in press) used a virtual reality-based procedure in order to assess deficits in spatial memory in the elderly. Virtual reality allows different functionalities and different interaction techniques. Smith, Salvendy and Koubek (1997) exposed two most prevalent interaction techniques in virtual reality with respect to the needs of elderly: how to navigate and how to select and manipulate objects in a 3D virtual environment. When implementing these techniques in a virtual environment, the usability of the interaction and of the input devices should be considered. The input devices are the tools used to implement the interaction techniques and they have to be natural, efficient and appropriate to work with a given technique (Smith, Salvendy and Koubek, 1997). Fisk et al. (2004) described the "usability" as the possibility and the facility to have access to a product in terms of learnability, efficiency, memorability, errors and satisfaction for older adults.

In line with Fisk, Holzinger, Searleand and Nieschelwitzer (2007) described three objectives when designing a new technology for older adults: the need to be adapted to the end user's physical impairments, the degree of familiarity and satisfaction with regards to the device, and the appreciation of the benefit when using this interface. The golden rule in order to interact naturally with a virtual environment is a natural user interface, which is an interface that is easy to use immediately, without the need for any training or previous experience (Steinberg, 2012).

Furthermore concerning the older adults, any changes with the main cognitive abilities due to aging, such as, perception, attention, memory and other functions involved in everyday life, should be taken into account in order to ensure the usability of a given interface (Gamberini et al, 2006). This last point is important for the special uses of virtual reality, like serious games based intervention for early dementia. Recently, there is an effort in literature to develop recommendations in order to design virtual reality for early dementia. Levels of

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difficulty, different layouts, errorless learning, simple and structured interfaces and scenarios, appropriate feedback and challenges are the common usability guidelines to design people centred rehabilitation using a virtual environment (Nor Wan Shamsuddin, Lesk and Ugail, 2011; Kaklanis, Moschonas, Moustakas and Tzovaras; Mader, Dupire, Guardiola and Natkin, 2012; Bouchard, Imbeault, Bouzouane and Menelas, 2012).

However all these studies above, although they investigate the usability of the game itself, do not evaluate the more appropriate interface to interact with the game.

The aim of the present study is to investigate how elderly can interact with three natural user interfaces and two standard input devices commonly used in the literature, as a first step to design a serious game based intervention for early dementia.

2. METHODOLOGY

2.1 Rehabilitation system

When working with the special target group of the elderly people, the ultimate goal is to support social interaction through customized user interaction scenarios and user interfaces. This requires strengthening their higher cognitive functions and everyday skills in realistic 3D VR environments. Our previous studies showed that Virtual Reality Daily Activities environments can be used to screen for persons with Alzheimer's disease early (Tarnanas et al, 2013) and if the diagnosis and treatment begins at a very early phase of the disease, they are able to manage their everyday activities longer and they suffer from less psychological and behavioural symptoms.

The 3D Memory Island virtual environment is a virtual reality journey back in time (auto-biographical memory) to landmarks that seniors have previously visited at their lives. We conducted an online survey regarding the most famous or visited cities or landmarks a typical Swiss senior might know or even have visited in his life. See figure 1 for examples of landmarks according to our survey. Based on the above, emphasis is given to tasks that have to be performed at the 3D Memory Island environment incorporating problem–based activities: for instance to prepare a virtual meal, to go shopping for ingredients, to navigate to the landmark etc. The aim of the 3D Memory Island is providing the users the capability of performing everyday activities with virtual reality by assisting the brain to find out alternative methods to execute functions, which are controlled by damaged brain regions. We also place a special focus on adaptive difficulty levels, allowing error-free learning that is expected to increase motivation, fun, and self-confidence.

Figure 1. *A virtual navigation at the 3D Memory Island until the user reaches the Parthenon landmark.*

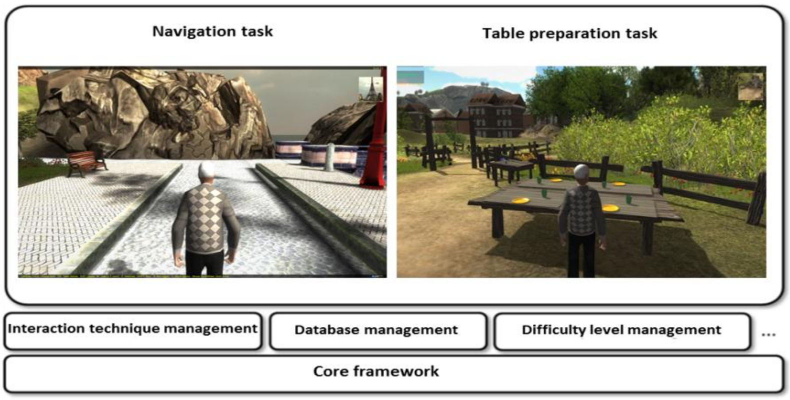

Figure 2. *A system framework of the 3D Virtual Memory Island.*

The proposed system: the 3D Virtual Memory Island is an immersive virtual reality platform which employs third-person view interaction. The current system consists of four main frameworks such as: Cognitive task and Interaction technique management framework, Database management framework and Difficulty level management framework (Figure 2).

2.1.1 Cognitive task and Interaction technique management framework. The Cognitive task management framework enables to manage two currently available training tasks such as the Table preparation task, and the Navigation task.

The therapist predefines the starting point and end goal for the Navigation task. The selected goal is displayed on the right-top of the main screen. A patient is required to reach the selected goal by using the connected interaction techniques. These interaction techniques enable the selection of 5 different types of interaction devices such as an optical natural user-interaction sensor, 2 magnetic natural user-interaction sensors, a Joystick and a Touchpad. Each interaction device is described in the section below.

If the patient chooses the wrong path on the way to the selected goal, the system recognizes the wrong path as error behaviour and indicates warning effect by changing the colour of the background of the screen.

2.1.2 Database management framework. The Database management framework enables the management of the system profile data, such as the task difficulty parameters as well as performance data that are collected during the applied cognitive task. This data set can then be visualized with various graphs and plots. This framework allows the patient and the therapist to monitor the progress of the applied training as well as to evaluate the effect of the task.

2.1.3 Difficulty level management framework. The Difficulty level management framework enables to manage the task difficulty. Currently, the task difficulty level is only changed manually by the therapist based on a patient's progress.

2.2 Study I

The goal of this study was to compare the usability of four interfaces using a navigation task. The following section describes the selected participants, the materials, the procedure and the data analysis of the first study.

2.2.1 Participants. 11 men and 9 women aged 60 to 86 were recruited through the Senior University of Berne to participate in this study (age M = 73; SD = 6.96). All subjects were used to handle computers; however none of them had experience playing video games.

2.2.2 Materials. The experimental setup consisted of a PC (Intel Core i7-3770 CPU with 3.40 GHz) with a 21" Asus screen (1920x1080, ASUSTeK Computer, Taïwan, CHINA) and 4 different interfaces (see figure 3): a Joystick (Logitech, Lausanne, VD, SUISSE), a Touchpad (Microsoft Corp, Seattle, WA, USA) and two motion and orientation detection game controllers, a Razer Hydra magnetic natural user-interaction sensor (Razer, San Diego, CA, USA), and a Kinect optical natural user-interaction sensor (Microsoft Corp, Seattle, WA, USA). The virtual environment was developed using the system Unity 3.4 which was the game development ecosystem.

To compare the different interfaces, the System Usability Scale (Brooke, 1996), a questionnaire developed to evaluate the effectiveness, the efficiency and the participants' satisfaction of different interfaces, was chosen. It includes 10 affirmations (i.e. "I thought the system was easy to use", "I found the system unnecessarily complex") and participants have to indicate their degree of agreement or disagreement on a 5 Likert scale. For the purpose of the study this questionnaire was translated to German.

2.2.3 Procedure. Each participant tried out all four interfaces in a counterbalanced order. The task was to guide an avatar through a pathway to reach a goal by following the navigation signs along on the way.

Two virtual scenarios were created to test the four interfaces. Both scenarios were set at 3D Memory Island, where the user starts from a give point and navigates freely in order to reach a modern or ancient landmark following the pathway explained above. The participants were instructed to reach those landmarks as fast as possible.

In one scenario, subjects were asked to reach a building which represented the Greek temple on the Athenian Acropolis, Parthenon (Snook et al, 2011) .The long-range-field-of-view optical sensor (Kinect) and the magnetic natural user-interaction sensor (Razer Hydra) were tested using this scenario. Subjects had to point their arms towards the desired direction to guide the avatar. Participants were asked to navigate the virtual environment by using only the mini joystick function of the Razer Hydra controller.

In the second scenario, subjects were asked to reach a group of four persons near to the Eiffel Tower with the use of the Joystick and the Touchpad. In order to guide the virtual character with the Touchpad, participants

Figure 3. *First Study experimental Setup (from left to right: the Razer Hydra, the Joystick, the Touchpad and the Kinect).*

moved their finger with several forward small movements. The Joystick was used without the need of using any additional button, as the three other devices.

Time to achieve the goal for each device was measured from the moment when the avatar started to move until the goal was reached. In both the scenarios, the goals were at the same distance from the starting point, which allows a comparison of the time between each interface. Moreover both the scenarios had the same paradigm, namely a navigation task, which allows the comparison of the satisfaction to use the devices, regardless to the scenario. Once one goal was achieved, the next interface was tried. After testing all four interfaces, participants filled out the System Usability Scale for each device individually.

2.2.4 Data analysis. Data analysis was performed using SPSS 20.0 for Windows (IBM corporation, New York, USA). As the data were not normally distributed and the satisfaction dependent variable was measured in an ordinal level, including a Likert Scale, a non-parametric analysis of variance (Friedman's ANOVA) was used to compare the mean score and the mean time among each interface. To adjust for multiple comparisons, the Bonferroni procedure was applied. A Spearman correlation was used to investigate if there is a link between the score on questionnaire and the time needed to achieve the goal.

2.3 Study II

The goal of this study was to compare the usability of two interfaces using a table preparation task. The following section describes the selected participants, the materials and the procedure. The data analysis was the same as the first study.

2.3.1 Participants. 11 men and 5 women aged 65 to 72 were recruited through the University Hospital of Tokyo, Japan to participate in this study (age M = 68; SD = 2.76). All subjects were used to handle computers; however none of them had experience playing video games.

2.3.2 Materials. The experimental setup consisted of a PC (Intel Core i7-3770 CPU with 3.40 GHz) with a 21" Samsung screen (1920x1080, Samsung corporation, Taegu, KOREA) and 2 different interfaces: a Razer Hydra magnetic natural user-interaction sensor (Razer, San Diego, CA, USA), and a LEAP motion magnetic natural user-interaction sensor (Leap motion Corp, San Francisco, CA, USA). The virtual environment was the same as in study 1.

As the table preparation needed other more precise measures to evaluate the task, the NASA-TLX was the chosen questionnaire for this task. Participant had to evaluate the task on 6 criteria in a 21 Likert scale.

2.3.3 Procedure. Each participant tried out the two interfaces in a counterbalanced order. The table preparation task was an exercise in order to prepare the kitchen table for two people dinner using the available kitchenware presented at the scene. The goal is to place the kitchenware at the correct positions at the table (accuracy) at the fastest possible time (executive functions / reaction-time). The table preparation task is shown at Figure 4.

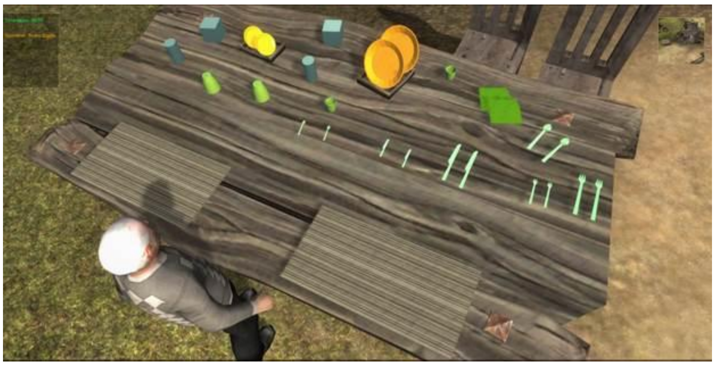

Figure 4. *Table preparation task.*

3. RESULTS

The number of participants, the mean score and the mean time per each interface are presented in table 1.

Table 1. *Mean score and mean time for each interface*

Interfaces	N	Score *		Time **	
		M	*SD*	*M*	*SD*
(a) Navigation task					
Joystick	20	86.36	(23.89)	214	(28.11)
Touchpad	20	54.62	(30)	213	(180.62)
Kinect	20	20.63	(19.63)	421	(143)
Razer Hydra	20	61.5	(28.32)	340	(71.42)
(b) Table preparation task					
Razer Hydra	16	3.16	(0.78)	67	(17.23)
Leap Motion	16	4.24	(0.78)	130	(33.48)

* Score from 0 to 100 for navigation task and from 0 to 7 for table preparation
**Time in seconds

First study Friedman's ANOVA revealed a significant main effect of score *(p* < .001) and of time *(p* < .001).

Orthogonal pairwise comparisons showed that the Joystick was significantly preferred (*M*= 86.38) than Touchpad (*M*= 54.63), Kinect (*M* = 20.63) and Razer Hydra (*M*= 61.50). No significant difference between the Touchpad score and the Razer Hydra score was found. The Kinect was significantly the less preferred in comparison to the three other interfaces. The goal was significantly reached earlier with the Joystick (*M*= 214) and the Touchpad (*M*= 213) than with the Razer Hydra (*M*= 340) and the Kinect (*M* = 421).

Only one negative correlation was found between the satisfaction to use the Kinect and the time to achieve the goal with the Kinect (r = -.573, p = .008).

Second study Friedman's ANOVA showed a significant main effect of score (p = .003). Subjects preferred to use the Leap Motion (*M* = 4.24) than the Razer Hydra (*M* = 3.16). A main effect of time was also found, *(p* < .001). Participants were significantly faster to complete the table preparation with the Hydra Razer (*M* = 67) than with the Leap motion (*M* = 130).

4. DISCUSSION

The aim of this study was to investigate what natural user-interaction interfaces are preferred by the elderly in a 3D virtual environment, as a first step to develop a serious game based intervention for early dementia. The Joystick was the favourite for the navigation task, while the Leap Motion was the favourite for the table preparation task. Fidopiastis, Rizzo and Rolland (2010) showed how important it is to choose a user centred design study that includes benchmarking for the efficacy of the virtual environment based rehabilitation programs, as it was in our study.

The present results show that the preferred interface is task dependent. Natural User Interfaces should be natural to use, which means representative of what we do in reality. They allow the user to directly interact with the computer. Leap motion and Kinect have the same principle which is to react to physical movements and gestures. The Razer Hydra controller can be related to widely used device such as the Wii and be used in two different ways, one is directly interacting and manipulating items on the screen via gesture recognition and pointing, the other is like a joystick, as it was done in the present study. But depending on the task and on the way to use it, the opinion and acceptance of the device was different. Navigation requires other movements and skills than table preparation and the interface should support the natural movements and skills to execute the task. The Kinect gestures we used were extending and pointing the arm forward in order to move the avatar forward which is not a natural movement for the human. As pointed out by Ball, North and Bowman (2007), the problem with a navigation task in 3D virtual environment is to immerse the user entirely in a virtual world and completely hide the physical world. When user's movements in the real-world accurately map the movement of the avatar in the virtual world then there is no feeling of disconnection. When it doesn't exist, disconnect arises when users must physically navigate in the real world in order to move in the virtual world. Physical navigation would have to be virtualized to match the virtual world, and this is difficult to fully achieve.

In contrast, the reality of the movement to take and displace an object was well represented by the use of the Leap Motion.

The literature shows many studies with the benefits of the Kinect and the Wii on elderly and clinical population (for Kinect see: Chiang, Tsai and Chen, 2012; de Urturi Breton, Zapirain and Zorrilla, 2012; Garcia, Felix Navarro, Schoene, Smith and Pisan, 2012; Obdrzalek et al, 2012 ; for Wii see: Clark and Kraemer, 2009; Fenney and Lee, 2010 ; Gerling, Schild and Masuch, 2010; Grosjean et al, 2010 ; Jung et al, 2009; Neufeldt, 2009). The general conclusion of all these studies is that the Wii and the Kinect support specific cognitive skills enhancements through the required physical movements. Moreover in patients' studies, they are found to be fun to use, which increases the level of motivation and encourages a long-term rehabilitation. Leap motion also seems to be a promising natural interface for virtual environment based rehabilitation programs. To our knowledge only one study used the Leap Motion with a virtual environment as a screening tool for early dementia (Tarnanas et al, 2013). Last decade the Joystick has been replaced by the motion and orientation detection game controllers in the field of virtual reality (Bowman, McMahan, and Ragan, 2012). A reason for that could be that Joystick is not as natural as the Kinect or the Wii to interact with virtual environment. Nevertheless, in the present study, it was popular among all participants.

According to Steinberg (2012) completion time is very important as "the users are impatient and do not want interfaces that take forever to navigate". The present results go partially with this idea because the Kinect was the interface with the longest time of achievement and the less liked. In line with the Fitts' law (1954), time indications and time of completion differences among all participants who used the same device can be a good indicator of the acceptance and user-friendliness of that device. The time standard deviation for the touchpad indicates that some participants used this device very easily whereas other had more difficulties. This difference can be based on experience that participants had with the touchpad of a laptop for example. In contrast, Joystick had a very small time standard deviation, all the participants used this device easily and didn't need any previous experience.

Furthermore Buxton (1994) considered technology in terms of the fidelity with which it reflects human capabilities on the physical, the cognitive and the social level. This is even more relevant when participants are old and not used to interact with technologies. Commercial-off-the-shelf (COTS) hardware used for this study, such as the Joystick and the touch mouse, are interaction devices with which older people have some familiarity because they are available to the public. Those devices manipulate position and orientation with two degrees of freedom. One the other hand, the magnetic and optical sensor natural user interfaces used enable 3D spatial interaction more efficiently than the COTS because they manipulate position and orientation with six degrees of freedom. All the interfaces had some usability freedom in terms of workspace and dexterity. Participants had the possibility to choose where they preferred to use the device and as each device required one hand to use it, participants were asked to use the preferred hand. The Joystick and the Razer Hydra were generally used directly in front the participants, whereas the Touchpad was usually used on the right or left side, depending on the participants' preference. The Kinect was either placed in the right side or in the left side, in front of the participant.

On the physical level, as elderly have reduced fine motor control but not reduced force control (Contreras-Vidal, Teulings and Stelmach, 1998), it is clear why they preferred to use the Joystick than the Touchpad or the Razer Hydra which required finer motor skills. Indeed the Joystick required more force but less fine control whereas the touchpad was used with small, accurate movements and the device was very sensitive. The Razer Hydra was also sensitive since participants had to be very precise in order to move the avatar straight forward. Even if the Kinect didn't require small and precise movements, the device was tiring for participants because of the unnatural gestures. In term of motor skills patient with early Alzheimer perform worse on tasks involving fine and complex motor function but not on gross motor tests in comparison to aged matched healthy adults (Kluger et al,. 1997).

5. CONCLUSION

This study provides the first comparison among five natural interfaces in two different virtual reality tasks and demonstrates that the goodness of a device with regards to the completion of an assigned task strongly depends on the task itself and on the abilities of the users. It confirms that the combination of several devices creates a range of interaction possibilities in order to suit with the needs of tasks and subjects (Hand, 1997).

Further studies in the field of user natural interfaces in 3D system are needed to allow interactions with the simultaneous use of two hands for input as it has been recognized as beneficial by Buxton and Myers (1986).

In conclusion, in order to create a serious game based rehabilitation program it is essential to take into account the usability of the involved devices, the patient's abilities and also the motivations to play of the target population.

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Unity 3D Game Development Tool, available at http://unity3d.com.

An integrative virtual reality cognitive-motor intervention approach in stroke rehabilitation: a pilot study

A L Faria[1], A Vourvopoulos[2], M S Cameirão[3], J C Fernandes[4], S Bermúdez i Badia[5]

[1,2,3,5]Madeira Interactive Technologies Institute, [2,3,5]Centro de Ciências Exatas e da Engenharia,
Universidade da Madeira
Funchal, PORTUGAL

[1]Faculdade de Psicologia e de Ciências da Educação, Universidade de Coimbra,
Coimbra, PORTUGAL

[4]Serviço de Medicina Física e Reabilitação do Hospital Nélio Mendonça,
Funchal, Madeira, PORTUGAL

ana.faria@m-iti.org, athanasios.vourvopoulos@m-iti.org, monica.cameirao@m-iti.org,
jeanclaudefml@gmail.com, sergi.bermudez@m-iti.org

ABSTRACT

Stroke is one of the most common causes of acquired disability, leaving numerous adults with cognitive and motor impairments, and affecting patient's capability to live independently. In post-stroke it is imperative to initiate a process of intensive rehabilitation and personalized objectives to maximize functional cognitive and motor recovery. Virtual Reality (VR) technology is being widely applied to rehabilitation of stroke, however, not in an integrative manner. Like traditional rehabilitation, these new tools mostly focus either in the cognitive or in the motor domain, which can take to a reduced impact in the performance of activities of daily living, most of them dual-task. Assuming the existence of cognitive and motor recovery interdependence, RehabNet proposes a holistic approach. Here we present a one-month long pilot study with three stroke patients whose training was a game-like VR version of the Toulouse-Piéron cancellation test, adapted to be performed by repetitive arm reaching movements. A standardized motor and cognitive assessment was performed pre and post intervention. The first results on this intervention support a holistic model for rehabilitation of stroke patients, sustaining interdependence on cognitive and motor recovery. Furthermore, we observed that the impact of the integrative VR approach generalizes to the performance of the activities of daily living.

1. INTRODUCTION

Stroke is the second largest cause of death worldwide and remains one of the leading causes of acquired disability in adults (WHO, 2014). The impairments to neuromuscular performance such as fine and gross motor control, muscle strength, and power are the consequences of stroke that have the greatest impact on functional capacity (Odier and Michel, 2009). However, stroke derived cognitive deficits also affect a person's capability to carry out activities of everyday living and their ability to live independently (Langhorne, Bernhardt, and Kwakkel, 2011). Cognitive impairments following stroke are common, and are present in approximately 70% of patients in the acute stages of recovery (Morris, Hacker, and Lincoln, 2012). The nature and severity of cognitive deficits varies according to several factors, such as location and extension of the lesion, type of stroke, comorbidities, complications, and may include problems with memory, perception, language, attention and executive functioning (Nudo, 2007). There is not a consistent profile of cognitive deficits after stroke, though slower information processing and executive dysfunction tend to predominate (Cumming, Marshall, and Lazar, 2013).

Rehabilitation programs based on intensive and customized treatment are important for improved functional recovery (Ganguly, Byl, and Abrams, 2013). Particularly, the persistent repetition of specific learning situations, which is standard practice in stroke rehabilitation, has been shown to lead to the re-organization of damaged cortical networks (Saleh et al, 2011). However, traditional stroke rehabilitation has some limitations, such as being labour and resource-intensive, at times demotivating and often resulting in modest and delayed effects in patients (Langhorne, Coupar, and Pollock, 2009). The limitations of traditional methods have inspired the development of Virtual Reality (VR) tools to increase treatment adherence and promote neuroplasticity by enhancing the effectiveness of traditional treatments. VR technology provides one of the most advanced interactions between humans and computers and, in the last decade, interest in its application to rehabilitation has increased substantially (Laver, George, Thomas, Deutsch, and Crotty, 2012). In particular, training cognitive and motor domains by means of gaming approaches is gaining increased clinical acceptance in the therapy of patients post-stroke or traumatic brain injury because of the ability of these tools to motivate patients, as well as to promote sustained movement practice (Albert and Kesselring, 2012).

Rehabilitation after stroke can be compromised because of cognitive-motor interference (Plummer et al, 2013). That is, in the cognitive domain, motor impairments can make hard or impossible the completion of cognitive exercises and in the motor domain patients might have difficulties in understanding instructions due to cognitive impairments. Hence, simultaneous (dual-task) performance of a cognitive and a motor task can result in deterioration of performance relative to performance of each task separately (Plummer et al, 2013). Moreover, activities of daily living are rarely exclusively motor or cognitive but a combination of both. So, a diminished capacity for dual-task performance may significantly impede functional independence and community participation.

Despite of the reported interdependency between cognitive and motor domains (Kizony, Levin, Hughey, Perez, and Fung, 2010), current methods for their rehabilitation are generally done separately and by different health professionals, and sometimes even in different clinical departments. The same trend has been observed in VR rehabilitation, with most of the approaches focusing either on motor [*Video Game–Based Exercises for Balance Rehabilitation* (Betker, Szturm, Moussavi, and Nett, 2006); *Rehabilitation Gaming System* (Cameirão, Bermúdez i Badia, Duarte, and Verschure, 2011); SeeMe System (Sugarman, Weisel-Eichler, Burstin, and Brown, 2011); IREX System (Kim, Chun, Yun, Song, and Young, 2011)] or cognitive [*LabPsicom* (Gamito et al, 2012); *Virtual Action Planning - Supermarket* (Josman et al, 2014); *The Virtual Street Crossing System* (Navarro, Lloréns, Noé, Ferri, and Alcañiz, 2013)] rehabilitation, disregarding issues like dual-tasking, a key factor for the ecological validity of the task.

We argue that novel VR approaches should focus on integrative cognitive and motor therapy based on games that pose both cognitive and motor demands. Assuming the interdependency between the recovery process of cognitive and motor domains, we may provide a more ecologically valid rehabilitation tool. As a consequence, we may have a greater impact in the recovery of independence, with the consequent impact in the performance of the activities of daily living. Here we present the results of a pilot study with three stroke patients who went through one-month intervention with a cognitive-motor training system operationalized in VR, the RehabNet. RehabNet aims at building a neuroscience based interactive toolset for stroke rehabilitation (Vourvopoulos, Faria, Cameirao, and Bermudez i Badia, 2013), merging together the cognitive and the motor training, in a holistic approach. RehabNet enables users with disabilities to interact with virtual environments in a way that they would not be able to do in the real world. Through different interaction interfaces, it enables motor impaired patients to generate meaningful goal oriented motor actions to recruit the neural networks responsible for action recognition, the mirror neurons (Rizzolatti, Fabbri-Destro, and Cattaneo, 2009). RehabNet combines VR with a gaming approach to allow patients to be active agents in the rehabilitation process by providing a totally controlled environment and an intensive training targeted to their deficits.

2. METHODS

2.1 Participants

Participants were recruited at the Physical Medicine and Rehabilitation Department of Nélio Mendonça Hospital (Funchal, Portugal) based on the following inclusion criteria: chronic stroke; first event ischemic stroke; no hemi-spatial neglect; non-aphasic and with sufficient cognitive ability to understand the training task instructions, Mini-Mental State Examination (MMSE) ≥ 15 (Folstein, Folstein, and McHugh, 1975) Portuguese version (Guerreiro et al, 1994); and ≥ 2 years of schooling. The sample consisted of three stroke patients with both cognitive and motor deficits (Table 1). The study was approved by the Madeira Health Service Ethical Committee and all the patients gave previous informed consent.

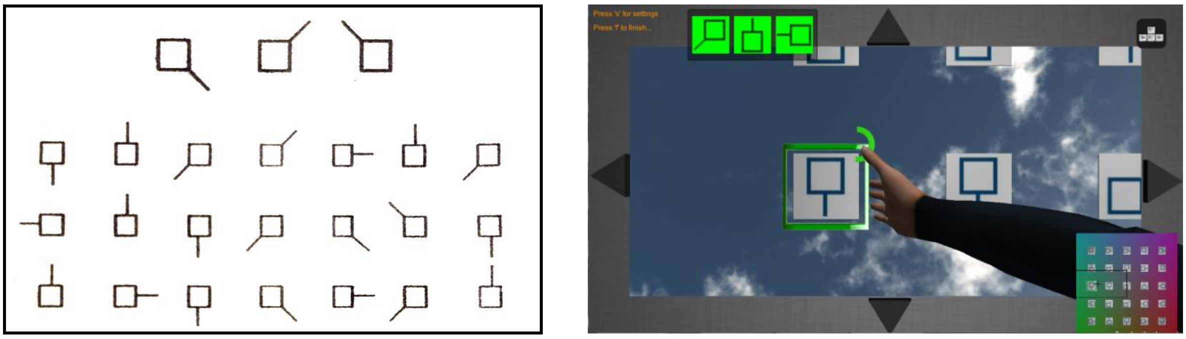
2.2 Cognitive-Motor Virtual Reality Task

Traditionally, motor rehabilitation of the upper-limbs focuses on strength, power, motor control and tonicity through a combination of physical and occupational therapy. On the other hand, cognitive rehabilitation is made through paper-and-pencil tasks, usually a specific task for each cognitive aspect, e.g. cancellation tests for selective attention. The Toulouse-Piéron (TP) test (Piéron, 1955) (Figure 1a) is among the most widely used cancellation tests to assess and/or train attention but, it can be of difficult or even of impossible execution for hemi-paretic stroke patients because of the motor deficits. Simulating some of the exercises used in traditional therapy, our training task consists of a game-like VR version of the TP test, (Figure 1b) adapted to be performed by repetitive arm reaching movements on a table top surface, and implemented by using the representation of the paretic arm for navigating and targeting symbols arranged in two dimensions.

Table 1. *Participant's demographics.*

	Patient 1	**Patient 2**	**Patient 3**
Age	47	72	46
Gender	Male	Female	Female
Schooling	4 years	2 years	6 years
Time after stroke	10 months	6 months	5 months
Hemisphere	Left	Left	Left

The training scenario has a build-in calibration function that is able to compute the active range of motion of the patient, normalizing the motor effort required to the skill set of the patient (Vourvopoulos et al, 2013). Two natural user interfaces [Kinect® (Microsoft Corporation, Washington, USA) for 3D movement and a custom made color tracking software (AnTS; Mathews, Badia, and Verschure, 2007) for 2D arm movements] and two pointing devices (mouse for 2D and airmouse for 3D movements) were used as interfaces by all patients in a random order. The four interfaces had the same selection method of the targets, which was a timer (Figure 1b). The intervention protocol entailed, in addition to conventional rehabilitation, twelve training sessions of twenty minutes, three times a week.



(a) *(b)*

Figure 1. *Representation of the paper-and-pencil (a) and virtual (b) modalities of the Toulouse-Piéron test.*

2.3 Cognitive and Motor Assessment

Before starting the intervention, cognitive and motor functions were assessed to obtain baseline measures. The same assessments were made at the end of the intervention. To capture the full scope of impairment and functionality, a number of cognitive and motor standard scales were used. All of them are widely applied clinically and in research to determine disease severity, describe cognitive and motor recovery, and to plan and assess intervention.

The analysis of the pattern of cognitive impairment was made through the Addenbrooke Cognitive Examination - Revised (ACE-R) (Mioshi, Dawson, Mitchell, Arnold, and Hodges, 2006) Portuguese version (Simões, Pinho, Sousa, and Firmino, 2011), a scale that covers a wide range of cognitive impairments by providing normative data for five subscales (attention, memory, verbal fluency, language and visuo-spatial capability), and also includes the MMSE (Morris et al, 2012). The task-related capabilities were assessed extensively with additional specific measures, such as: the Trail Making Test A and B (TMTA / TMTB) (Reitan, 1958) Portuguese version (Cavaco et al, 2013) for selective and divided attention, mental flexibility and motor speed; and the Coding subtest from the Wechsler Adult Intelligence Scale III (Wechsler, 2008) for visual-motor coordination, motor and mental processing speed and visual working memory. A short version of the TP test

(Piéron, 1955) was included to compare the performance on paper-and-pencil and the performance on the virtual environment. Performance was assessed with the following formula: TP = correct – (omissions + errors) / symbols x 100. The tests were delivered in the presented order, this is, we started by the screening scale, followed by the specific measures and finally, the paper and pencil TP.

A physician performed functional assessment such as the Fugl-Meyer assessment, the Barthel Index, the Functional Independence Measure (FIM) and the Medical Research Council (MRC) strength evaluation scale. The Fugl-Meyer assessment is a well-established measure of function impairment after stroke in 5 domains (motor, sensory, balance, joint amplitude and pain) of both upper and lower-limb, and can be adapted to evaluate the upper-limb (Gladstone, Danells, and Black, 2002). The Barthel Index and the FIM are commonly used scales to measure disability in activities of daily living (D'Olhaberriague, Litvan, Mitsias, and Mansbach, 1996), (Grimby et al, 1996). The MRC scale, which is widely used for Manual Muscle Testing (Paternostro-Sluga et al, 2008) was used for assessment of upper-limb muscle groups.

To assess patients' subjective opinions with respect to a number of aspects of the intervention with RehabNet, a 5-point Likert scale self-report questionnaire (Cameirão, 2010) was used at the end of the intervention.

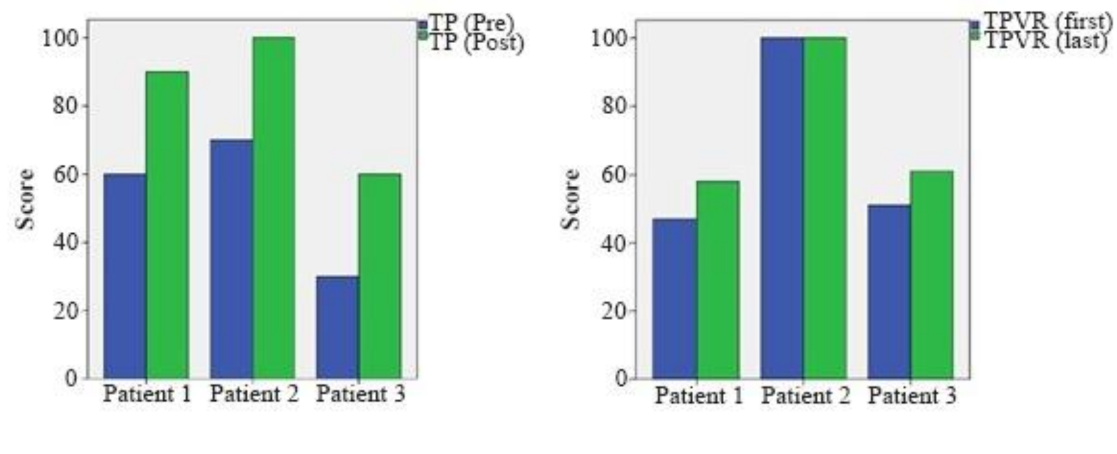
2.4 Data Analysis

The baseline measures of the cognitive and motor scales were quantitatively compared with the post-intervention results in all these clinical measures. Overall, the data analysis was qualitative because of the sample size.

3. RESULTS

3.1 Can a paper and pencil assessment/training task be transferred to the virtual environment and have the same impact? Is training equivalent?

In order to overcome the motor limitations and allow the cognitive assessment and/or training, we had the TP test operationalized in virtual reality in the RehabNet system. All patients were exposed to all the interfaces in a random order. At the end of the one-month intervention, we observed improvements, from pre-intervention to post-intervention, in all patients when evaluated with the paper-and-pencil version of the TP test. Patient 1, 2 and 3 increased from 60% to 90%, 70% to 100%, and 30% to 60%, respectively (Figure 2a). These outcomes, together with the performance progress of patient 1 and 3 in the virtual task (patient 2 had already reached the maximum score in the first session and therefore can not improve any further) (Figure 2b), suggest that despite the necessary VR adaptations to embrace a motor-cognitive integrative training, there is a transfer between the gains in VR and the ones assessed by the paper-and-pencil. The improvements were higher in the paper-and-pencil task probably because in the VR task the motor deficits were mitigated by means of the interfaces and their calibration.



(a) *(b)*

Figure 2. *Pre and post-intervention performance in the paper-and-pencil reduced version of TP test (a) and the first and last session performance in the VR version of the TP test (b).*

3.2 Does training with the RehabNet cancellation task improve cognitive domains related and non-related to the task?

In the cognitive domain, participants improved or reached the maximum score in memory and visuo-spatial ability, as assessed by the ACE-R, both domains targeted by RehabNet training task (Table 2). So, we can say there was a specific transfer of what participants have been training in VR to general improvements as assessed after the intervention by the cognitive assessment tools.

Table 2. *Cognitive assessment pre and post-intervention. Improvements are highlighted in bold.*

		Patient 1		***Patient 2***		***Patient 3***	
		Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
ACE-R	*Total*	**78**	74	93	**97**	57	**63**
	Attention	**18[1]**	15	18[1]	18[1]	16	**17**
	Memory	18	**19**	25	25	**11**	10
	Verbal Fluency	**7**	5	11	**12**	**6**	4
	Language	**25**	24	23	**26[1]**	13	**20**
	Visuo-Spatial	10	**11**	16[1]	16[1]	11	**12**
TMTA	*Time*	80	**76**	---	**66**	275	**137**
	Errors	0	0	---	**0**	4	**0**
TMTB	*Time*	257	**190**	---	**115**	---	**450**
	Errors	0	0	---	**1**	---	**3**
Coding (WMS)	*Coding*	12	**13**	---	---	**3**	**11**
	Learning	0	**6**	---	---	**0**	0
	Free Recall	2	**4**	---	---	**0**	**3**

1 Maximum score of the assessment instrument.

Participant 3 improved in attention/concentration, participant 2 had already reached the highest score in the pre-intervention assessment and participant 1 got a lower score. This last participant also did worse in language, whereas the other two participants improved in this domain that was not directly addressed by the RehabNet training.

At the pre-intervention assessment, participants 2 and 3 could not perform some of the cognitive scales because for the execution of these tasks they were required fine motor skills. Examples of these tasks are the TMTA and TMTB and the Coding from the WMS-III. In the TMT, which measures attention, mental flexibility and motor speed, participant 2 was not able to do it in the pre-intervention but did it in the post, needing a short time and making just one error. Participant 3 was not able to perform the TMTB in pre-assessment but did it in the post. The patient needed a short time and made 3 errors. Participant 1 performed very well in both assessments with this task, making better in the processing speed from the pre to the post-intervention. Participants 1 and 3 improved in the Coding task, which assesses visual-motor coordination and processing speed. Participant 2 was not able to perform the task in neither pre nor post-assessment. Participant 1 improved in the Incidental Learning and Free Recall tasks, which assesses visual working memory. Overall, these results suggest that our intervention improved some of the cognitive domains targeted by the system, and that for patients 2 and 3, we can say that there was a generalization of the rehabilitation process to cognitive domains non-related to the task.

In the motor domain, we can see general improvements for patients 2 and 3 (Table 3). Patient 2 and 3 had improved scores as assessed by the Fugl-Meyer scale in the upper-limbs and passive movement amplitude while patient 1 had a small recess. All patients improved or maintained in the Sensibility and in the Pain scores. In terms of arm strength, patient 1 improved it in the wrist flexion and extension, maintained in the shoulder flexion, extension and adduction with a small recess in the shoulder abduction, and also maintained in the elbow flexion and extension. Patient 2 was limited by pain in the pre and post-assessment of the shoulder, nonetheless, improved in the elbow and wrist both flexion and extension. Patient 3 was limited by pain in the pre-assessment of the shoulder, reaching the maximum score in the post-assessment. This patient maintained the maximum score for the elbow and wrist, flexion and extension, in both assessment moments. More importantly, all patients improved or maintained the score in the Barthel Index, meaning that this intervention had an impact in the performance of the activities of daily living in 2 of the 3 participants. Overall, these results suggest that our integrative intervention (Table 2 and 3) improved cognitive function – for some patients beyond the specifically trained domains – and also fine motor skills, which made possible the accomplishment of paper-and-pencil tasks that wasn't possible before.

Table 3. *Motor and Activities of Daily Living assessment pre and post-intervention. Improvements are highlighted in bold.*

		Patient 1		***Patient 2***		***Patient 3***	
		Pre	*Post*	*Pre*	*Post*	*Pre*	*Post*
Fugl-Meyer	*Upper-Limbs*	**50**	47	24	**38**	48	**59**
	Sensibility	8	**10**	7	**11**	12	12
	Passive Movement	**24**	23	20	**21**	23	**24**
	Pain	24	24	16	**18**	22	**24**
ADL's	*Barthel*	80	80	85	**95**	80	**95**
	FIM	114	113	113	**117**	115	**123**
MRC	*Shoulder flexion*	4	4	limited by pain	limited by pain	limited by pain	**5[1]**
	Shoulder extension	5[1]	5[1]	limited by pain	limited by pain	limited by pain	**5[1]**
	Shoulder abduction	5[1]	4	limited by pain	limited by pain	limited by pain	**5[1]**
	Shoulder adduction	5[1]	5[1]	limited by pain	limited by pain	limited by pain	**5[1]**
	Elbow flexion	5[1]	5[1]	3	**5**[1]	5[1]	5[1]
	Elbow extension	5[1]	5[1]	2	**5**[1]	5[1]	5[1]
	Wrist flexion	2	**3**	2	**3**	5[1]	5[1]
	Wrist extension	4	**5**[1]	4	**5**[1]	5[1]	5[1]

1 Maximum score of the assessment instrument.

3.3 *Validity of the holistic cognitive-motor RehabNet approach*

As already discussed, one of the main features of RehabNet system is the integration of the cognitive and motor training. All patients improved on specifically trained aspects of the task. Moreover, the two participants who improved in the overall ACE-R also had higher scores in the Fugl-Meyer (upper-limb) motor scores. Our data shows that the only patient that did not improve in the overall ACE-R did not improve either in the Fugl-Meyer. Our data shows congruent data in both motor and cognitive domains for all patients (Figure 3), being consistent with the premise of interdependency of recovery. Furthermore, it is common for patients to improve their scores on paper-and-pencil tests through practice, without showing an associated improvement in real life situations (Navarro et al, 2013). In our study, the improvements verified in the cognitive and motor scales also correlate with the improvement results in the Barthel Index, that is, in the performance of activities of daily living. Thus, our data is consistent with the idea that training both domains at the same time might have a boosting effect in the general rehabilitation process.

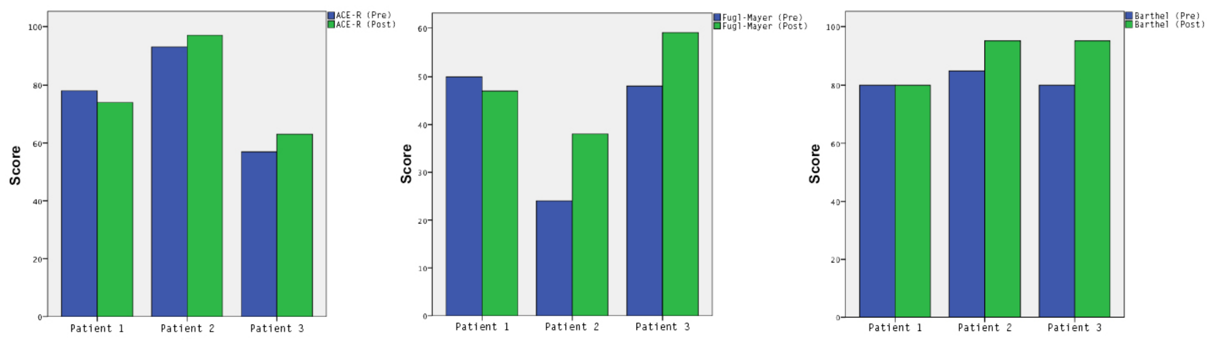


Figure 3. *ACE-R, Fugl-Meyer (upper-limbs) and Barthel Index results showing the interdependency between the cognitive, motor and functionality variables.*

4. DISCUSSION AND CONCLUSIONS

Here we presented a VR motor-cognitive dual training task and the results of a one-month intervention with 3 patients. In the cognitive domain, we find improvements in domains trained by the VR task, and the generalization of the improvements to other domains in 2 of the 3 patients. However, in the cognitive domain, these improvements were small (4 and 6 points) probably due to the low frequency and intensity of the training (12 sessions of 20 minutes). The improvements in the TP paper-and-pencil task are greater than those in the cognitive domain of the TPVR task, suggesting that cognitive and motor domain improvements are related. However this training rendered much greater improvements in the motor domain than in the cognitive domain. The results of this pilot are consistent with our hypothesis of a holistic model for rehabilitation of stroke patients. Further, we could observe in 2 patients that the integrative rehabilitation of both domains has an impact on the capacity of performance of activities of daily living.

We investigated further the case of patient 1, who even showed a recess in some assessment measures. While most patients are discharged from the rehabilitation programs six months after the stroke, at the moment of this paper, this patient is already at the Physical Medicine and Rehabilitation Department for fifteen months due to the poor impact of therapy. We found that patient 1 has a history of drug abuse, what might be one of the factors contributing for the unusual evolution.

Despite the limitations of the sample size and amount of training, the results of this study show improvements and emphasize the value of rehabilitation approaches that merge cognitive and motor domains in single tasks. In the future, we aim to increase the sample size to perform a more quantitative assessment of the impact of the RehabNet, and to implement more cognitive tasks targeting different cognitive functions, and assessing their impact in recovery following stroke by means of longitudinal clinical trials.

Acknowledgements: This work is supported by the European Commission through the RehabNet project - Neuroscience Based Interactive Systems for Motor Rehabilitation - EC (303891 RehabNet FP7-PEOPLE-2011-CIG), and by the Fundação para a Ciência e Tecnologia (Portuguese Foundation for Science and Technology) through SFRH/BPD/84313/2012 and SFRH/BD/97117/2013 and Projeto Estratégico - LA 9 - 2013-2014.

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Virtual reality-augmented rehabilitation for patients in sub-acute phase post stroke: a feasibility study

G G Fluet[1], A Merians[1], J Patel[1], A Van Wingerden[1], Q Qiu[1], M Yarossi[1], E Tunik[1], S Adamovich[1,2], S Massood[3]

[1]Department of Rehabilitation and Movement Science, Rutgers University
65 Bergen Street, Newark, NJ, USA

[2]Department of Biomedical Engineering, New Jersey Institute of Technology
University Heights, Newark, NJ, USA

[3]Acute Rehabilitation Unit, Saint Joseph's Wayne Hospital
224 Hamburg Turnpike, Wayne, NJ, USA

fluetge@shrp.rutgers.edu, alma.merians@shrp.rutghers.edu, patel421@shrp.rutgers.edu, vanwinam@shrp.rutgers.edu, qiuqi@shrp.rutgers.ed, yarsosma@shrp.rutgers.edu, tunikeu@shrp.rutgers.edu, adamovich@njit.edu, Smassood@sjwh.org

[1]*https://sites.google.com/a/njit.edu/raver_lab/?pli=1*

ABSTRACT

Upper extremity (UE) rehabilitation is of utmost importance to the achievement of full inclusion and functional independence. Traditionally presented as well as technology-based therapeutic interventions have produced measurable changes in motor function and motor control but fall short of major reductions in disability. Animal models of stroke suggest that the first two weeks to one month post stroke may be a critical time period of increased brain plasticity. This study shows the feasibility of adding one hour of intensive robotic/virtual reality (VR) therapy to on-going rehabilitation in the acute phase of recovery post-stroke. All five of the subjects made substantial improvements in Upper Extremity Fugl-Meyer Assessment (UEFMA) scores (mean improvement = 6 points (SD=2)) as well as improvements in Wolf Motor Function Test (WMFT) time (average decrease = 41% (SD=35) after training with more consistent changes in the proximal arm portions of the WMFT and the UEFMA as well as in upper arm kinematics. Maps of cortical excitability indicate an increase in both the area of activation and the volume of activation of the first dorsal interosseous (FDI) muscle after a two-week training period.

1. INTRODUCTION

People post-stroke exhibit paresis of the upper and lower extremities. When a person with paresis uses their upper extremity (UE) for purposeful movement, the paretic movements differ from normal movements in that they are slower, less accurate, have delayed or reduced force, and are uncoordinated in terms of magnitude and timing of the movement (Sathian, et al, 2011). Upper extremity rehabilitation is of utmost importance to the achievement of full inclusion and functional independence. Plasticity-mediated therapies have evolved from the concepts of adaptive activity-based neuroplasticity, task- oriented motor training and the need for high doses of repetitive practice. One approach to plasticity-based therapy the combination of of virtual reality and rehabilitation robotics has offered new promise for enhanced outcomes for upper extremity rehabilitation. The literature shows a progression of articles, from feasibility studies, to small clinical trials and a recent Cochrane review suggesting the potential benefits of using virtual reality for rehabilitation. However, to date, the best efforts of groups studying technology-based therapeutic interventions have produced measurable changes in motor function and motor control, but fall short of major reductions in disability.

The prevalence of studies in people with chronic CVA stands in contrast to animal models of stroke that suggest that there may be a critical time period of increased brain plasticity (Biernaskie, Chernenko, and Corbett, 2004). During the first month post stroke the peri-infarct cortex regains responsiveness to cortical afferents with accompanying increased dendritic spine morphogenesis and axonal sprouting (Krakauer, Carmichael, Corbett, and Wittenberg, 2012). Rats trained with daily sessions of reaching showed significant gains in forearm reaching ability when the training was started 5 or 14 days post infarct but not 30 days post infarct (Biernaskie et al, 2004). The important question these studies raise is whether early intensive training might be more effective.

To date only three studies have focused on task-based upper extremity interventions in persons in the acute period post-stroke. A study by da Silva Cameirão of persons less than thirty days after CVA, identified faster recovery of upper extremity motor function in patients performing virtually simulated rehabilitation activities (VSRA) for twenty minutes in addition to a standard inpatient rehab program (SIRP) when compared to controls who performed a dose matched increase in activity beyond their SIRP (da Silva Cameirão, Bermúdez i Badia, Duarte, and Verschure 2011). This finding is important because it establishes the feasibility of using VSRA in addition to an SIRP very early after a CVA.This study alsosuggests that VSRA might have an effect during the acute stages of stroke. The second study using a more traditionally presented intervention (CIMT) did not demonstrate additive benefits (Dromerick et al, 2009). A third study of subjects less than six months after a stroke by Levin demonstrated no difference in motor outcomes when comparing a group of subjects performing a nine session, VSRA program and a control group performing a dose-matched program of traditionally presented UE rehabilitation.

This study was designed to test the feasibility of training patients between one and eight weeks after a CVA using our intensive robotically facilitated, virtually simulated UE motor intervention (Adamovich et al, 2005; Fluet et al, 2012; Merians et al. 2011; Merians, Poizner, Boian, Burdea, and Adamovich, 2006). The intervention utilizes several innovative, technology based approaches such as simulated activities that adapt in difficulty based on patient performance, robotic antigravity support and trajectory shaping as needed and the virtual magnification of small active finger movements into meaningful virtual activities. We hypothesized that this intense, targeted intervention , would be tolerated well by persons in the first weeks following a stroke that were participating in inpatient or outpatient rehabilitation concurrently. In addition a battery of clinical, kinematic and neurophysiologic testing was performed to provide data to establish sample sizes for controlled studies of alternative treatments which will occur in the future

2. METHODS

2.1 Subjects

We performed feasibility testing with a single group of seven persons Subjects were recruited from a consecutive sample of patients from the in-patient department of a suburban hospital. After initial screening by the department's physician, a physical therapist screened subjects based on the following criteria: Inclusion: 1) within 2 months post stroke, 2) between the ages of 30 and 80, 3) partial active shoulder flexion, or abduction, elbow extension and wrist extension against gravity. 4) trace extension at the fingers (detected visually) that can be reproduced several times in a minute. Exclusion: 1) severe spasticity (Modified Ashworth 4), 2) cognitive deficits rendering them unable to follow three step commands or attend to task for at least ten minutes 3) hemi-spatial neglect rendering them unable to interact with an entire twenty four inch screen, 4) proprioceptive loss that rendered a potential subject unable to interact with a virtual environment without looking at their hand 5) unstable blood pressure and oxygen saturation responses to activity. A separate screening and consent process for the motor mapping evaluation using transcranial magnetic stimulation was conducted.

2.2 System

The NJIT RAVR System consists of an instrumented glove combined with the Haptic Master (Moog-NCS, The Netherlands), a 3 degrees of freedom, admittance controlled (force controlled) robot. Three more degrees of freedom (yaw, pitch and roll) are added to the arm by using a gimbal for pronation/supination (roll). A three-dimensional force sensor measures the external force exerted by the user on the robot. In addition, the velocity and position of the robot's endpoint are measured allowing the robotic arm to act as an interface between the participants and the virtual environments (described below), The Haptic Master allows one to program the robot to produce haptic effects, such as spring, damper and constant force and to create haptic objects like blocks, cylinders and spheres as well as walls, floors, ramps and complex surfaces. The users interface with the Haptic Master via a forearm trough that extends through the gimbal, allowing for partial support of the weight of the arm as needed, while maintaining the ability to produce and measure pronation and supination movement. The NJIT TrackGlove System consists of a CyberGlove™ (Immersion, USA), an instrumented glove for finger angle tracking, and a TrackStar™ three-dimensional magnetic tracking system (Ascension Technologies).

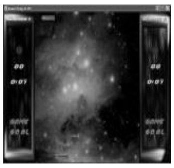
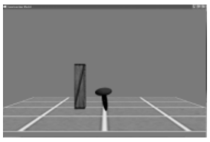
2.3 Simulations

We have developed a suite of simulations for training shoulder, elbow, wrist and finger movements using the Virtools software package (Dassault Systemes). See Table 1 for descriptions of simulations that were used and the movement constructs they target.

2.4 Training Protocol

To explore the feasibility of adding an hour of intense upper extremity activity to a standardized in-patient rehabilitation program, subjects received 60 minutes of training using the robot and the virtual reality gaming simulations in addition to their on-going in/out-patient physical, occupational and speech therapy for 5 days/week for two weeks.

Table 1. *Training Simulations.*

Simulation	**Training Goal**	**Game Play**	**Progression**	**Metric**
Monkey Business 	Improve pinch grip force modulation	Subject controls monkey with pinch grip. Height that monkey jumps is in proportion to force of pinch grip. Subject makes the monkey jump to branches of varying heights.	Height of jumps are increased and time between jumps decreases as time to successful completion of the task decreases	Time/Accuracy
Space Pong 	Finger Extension modulation	Subject plays a pong type game against the computer. Subject moves the paddle to the right by opening their fingers and to the left by closing them.	Decrease proportion of subject movement (finger extension) to paddle movement if accuracy does not improve with practice. Increase proportion when accuracy increases.	Accuracy
Space Ship 	Decreased arm elevation	Subject intercepts targets and avoids obstacles by piloting a spaceship with shoulder abduction and flexion movements	Increase target speed and obstacle density Increase workspace size as AROM increases.	Score increases with targets hit and obstacles avoided. Workspace size
Hammer 	Decreased Shoulder-Elbow Isolation	Subject hammers peg into the floor by pronating his forearm. Robot holds hammer stable over the target peg.	Decrease proportion of subject movement (pronation) to hammer movement as time to hammer pegs decreases	Peak pronation range of motion Time to hammer pegs
Piano 	Decreased Finger Individuation	Subject plays scales and simple songs. Each key is cued and the finger to press it designated.	Algorithm sets fractionation target based on performance. Utilize CyberGrasp™ to teach movement pattern if subject does not respond to algorithm.	Fractionation Time to press keys
Cups 	Decreased Shoulder-Trunk Isolation	Subject attaches virtual hand to virtual mugs and places them on virtual shelves in a 3-d workspace.	Increase volume of workspace as time to place cups on shelf decreases Recalibrate workspace weekly	Time to place nine cups on shelf Reaching trajectory length
Falling Objects 	Shoulder flexion towards midline	Subject moves a cursor to catch targets as they fall from the top of the screen. Targets drop centered on subject or in intact hemispace.	Recalibrate workspace weekly.	Time to catch 100 targets Height of targets caught

2.5 Outcome Measures

We examined the ability of our clinical, kinematic and neurophysiological measures to document changes in motor performance and neural control in persons having had their strokes less than thirty days prior to testing and training.

Clinical Assessment. Subjects were tested one day prior to training (pre-test) and one day after training (post-test). A physical therapist performed the Wolf Motor Assessment Function Test, (Wolf et al, 2001) and the upper extremity portion of the Fugl-Meyer Assessment (Fug l-Meyer 1979).

Kinematic Assessment. Pre/Post kinematic measures included changes in distal kinematics, proximal kinematics and force. All measures were collected with the patients seated with their trunks supported and their hands resting on a table. Performance for all tracing tasks was measured following a single familiarization trial which was not scored.

Finger angles were collected using a Cyberglove™ (Immersion, USA). **Finger range of motion** was measured as the difference between all of the joint angles with the fingers in a relaxed / flexed position and the joint angles of all of the fingers actively extending the fingers as much as possible. Larger differences indicated better active finger extension range of motion.

Finger Trace is the ability to modulate active finger extension and flexion between zero and eighty percent of max extension, measured by having the subject flex and extend their fingers to control a cursor tracking a sine function wave (period=.15 Hz, duration of 1 cycle≈ 6 seconds).Lower root mean square error values indicate better performance.

Shoulder and elbow coordination was measured by having the subject trace a figure of eight (diameter of each circle approximately 20cm, vertex at the midline of subject's body) on a low friction table top with their paretic hand. Lower root mean square error values indicate better performance. Hand path was measured with a TRACKSTAR™ three-dimensional magnetic tracker (Ascension, USA).

Pinch force was measured with an ATI Nano17™ force sensor (ATI Industrial Automation, USA). Pinch grip force is measured as the maximum voluntary force a subject can exert on a force sensor held between their paretic thumb and index finger, given two trials. Higher numbers indicate stronger pinch grip**.**

Pinch Trace is the ability to modulate pinch grip force between zero and eighty percent of max pinch force, measured by having the subject vary pinch grip force to control a cursor tracking a sine function wave (period=.15 Hz, duration of 1 cycle≈ 6 seconds). Lower root mean square error values indicate better performance.

TMS Mapping. Subjects were tested one day before the therapy onset and one day after the end of the therapy. Subjects were seated with their arm, hand, and fingers comfortably secured in a brace to limit motion. To assure spatial TMS precision, each subject's high-resolution anatomical MRI was used to render a 3D cortical surface that is co-registered with the subject's head for frameless neuronavigation (Advanced Neuro Technology). Transcranial Magnetic Stimulation (TMS) (Magstim Rapid2, 70mm double coil) was used to determine the hotspot for the contralateral first dorsal interosseus muscle (FDI). The TMS coil was held tangential to the scalp with the handle posterior 45° off the sagittal plane.Following determination of the FDI hotspot resting motor threshold (RMT) was calculated as the minimum intensity required to elicit MEPs >50μV in the FDI muscle on 50% of 6 consecutive trials (Butler, AJ et al. 2005). Surface electromyographic activity (EMG, Delsys Trigno, 2 kHz) was recorded from the FDI muscles of the limb contralateral to stimulation side.

Mapping was conducted on the lesioned hemisphere of both subjects. All mapping was performed with the subject at rest and stimulation intensity set to 110% of the determined RMT (Ngomoa, S et al. 2012) . A 10x10cm area surrounding the motor hotspot was marked using the neuronavigation software to provide consistent map boundaries. TMS pulses were delivered within the bounds with special attention paid to regions surrounding the hotspot territory. Real time visual feedback of the MEP time traces and neuronavigated coil position provided to the experimenter during testing maximized the map information obtained by allowing for increased density of points in excitable and border regions, with less attention given to far-away non-responsive areas (Niskanen, E et al. 2010). For each stimulation point we computed the following measures: (i) MEP as the peak-to-peak amplitude of the EMG signal 20-50ms after the TMS pulse, and (ii) background EMG, calculated as the EMG signal in the 50ms interval before the TMS pulse (2nd order Butterworth filter, 5-250 Hz band-pass, full-wave rectified, 20Hz low-pass envelope). A threshold of 50uV was used to identify MEPs from background EMG (Ngomoa, S et al. 2012). To allow comparisons across maps and sessions, MEP amplitudes and stimulation points were interpolated to a 10x10 cm mesh of 5 mm resolution centered on the M1 hotspot, using cubic surface interpolation (Borghetti, D et al. 2008, Weiss, C et al. 2012.) Outcome measures include map area and vlume, determined using double trapezoidal integration of the interpolated maps.

3. RESULTS

Table 2. *Initial Subject Characteristics.*

Subject	Age	Gender	Time Since CVA(Days)	Hemiplegic side	Lesion Location	Initial UEFMA total
1	67	M	47	R	MCA	43
2	62	F	39	R	Pons	25
3	57	M	6	R	Pons	30
4	57	M	5	L	Parietal	24
5	74	M	12	L	Cerebellum	55

We performed feasibility testing with a single group of seven persons. Training was initiated an average of 20 (SD=18) days post stroke. Average subject age was 63 (SD=6.3) years (See Table 2) Please note that subject numbers correspond to the same patients for Tables 2-5 and Figure 1. One subject discontinued the protocol after being screened but prior to testing due to a second stroke, a second discontinued training after one intervention session due to fatigue. The five remaining subjects completed 8 sessions of sixty to seventy five minutes of interaction with a set of 6 simulated rehabilitation tasks in addition to completing 100% of their scheduled SIRP treatment sessions (90 minutes of PT, 90 minutes of OT and 45-90 minutes of ST per day) during the study period suggesting feasibility of this protocol. No adverse events were noted during VR training. All five subjects were able to understand the simulations well enough to participate without extensive instruction in spite of a relatively simple screening process (one three step command). Two of the seven subjects could not participate in TMS testing due to a history of seizures and three more did not consent to participating in this aspect of the study.

All five subjects made substantial improvements in UEFMA scores (Mean improvement = 6 points (SD=2)) as well as improvements in WMFT time (average decrease = 41% (SD=35) (See Table 3). In addition, four of the 5 subjects completed at least one functional activity from the WMFT battery at posttest that they were unable to perform at pre-test. Four of the 5 subjects demonstrated improvements in clinical measures of proximal upper extremity function. In addition 3 of the 5 subjects demonstrated improvements in the kinematic measure of proximal UE coordination (Table 3). Distal UE function did not change as consistently. Only one of the five subjects demonstrated across the board improvements in all six measurements. Four of the five subjects demonstrated improvements in maximum pinch force. Four subjects demonstrated improvements in distal UEFMA. (Table 4). Fig. 1 shows the changes in the distribution of the pattern of activation for the first dorsal interosseous (FDI) muscle acquired pre and post training for two the two subjects from this sample that were appropriate for, and consented to TMS testing . The MEP maps indicate an increase in both the area of activation and the volume of activation after training.

Table 3. *Proximal UE Clinical and Kinematic Measurements.*

Subject	WFMT Proximal (sec)		UEFMA Proximal		Figure 8 RMSE	
	Pre	Post	Pre	Post	Pre	Post
1	11.5	13.46	35	40	3.66	2.67
2	135.7	15.7	28	33	17.39	1.49
3	128.03	30.51	19	23	1.15	1.39
4	376.14	251.43	10	17	11.36	13.72
5	12.67	11.51	23	24	1.35	0.55

4. DISCUSSION

This study demonstrated the feasibility of adding one hour of intensive robotic/VR therapy to on-going rehabilitation in the acute phase of recovery post-stroke. Five of the seven the subjects were able to participate in and tolerate the additional intensive activity with two of these five subjects beginning the robotic/VR therapy 5 days and 6 days post-stroke. Subjects vital sign responses to intense upper extremity activity remained stable throughout training. Subjects were supervised during 100% of the training sessions which is common for patients in the earliest phases of rehabilitation after a stroke.

Table 4. *Distal UE Clinical and Kinematic Measures.*

Subject	WMFT Distal (sec)		UEFMA Distal		Finger Range (deg)		Finger Trace RMSE		Pinch Force Max (N)		Pinch Trace RMSE	
	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post	Pre	Post
1	671.06	672.63	20	24	23.55	10.8	4.69	7.21	19.91	18.16	5.74	6.84
2	960.00	845.82	15	27	12.64	37.5	3.30	1.32	1.43	8.74	0.60	0.33
3	375.94	405.89	11	13	41.77	38.6	3.51	4.32	16.28	26.36	3.84	3.14
4	847.22	735.87	14	13	57.89	49.9	7.28	7.75	21.02	30.78	5.53	5.99
5	144.46	50.74	2	7	51.43	56.2	11.3	10.31	12.33	50.54	4.07	12.10

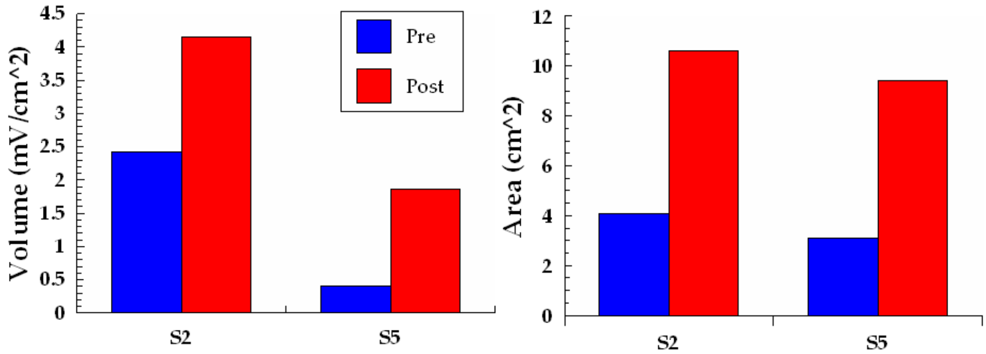


Figure 1: *Volume and Area of TMS maps of first dorsal interosseus muscle of paretic hand of two subjects (S2 and S5) measured before and after training.*

This study elucidated several important issues regarding determining the efficacy of such early intensive intervention. As a group the subjects showed a 41% change in the WMFT after the two-week training period. This change is double what we have found when training patients in the chronic phase (22%). It has been demonstrated that the effect sizes reported for several clinical measures (e.g the Frenchay, WMFT, TEMPA, ARAT, Jebsen) calculated at less than 3 months post-stroke were substantially larger than those calculated at three months or later post-stroke (Simpson and Eng, 2013). The authors speculated that the observed differences in effect sizes during this time period likely reflect the inherent neuroplasticity early after stroke. However, when subjects' outcomes were examined individually there was a noted variation in their response to treatment. Overall, there were more consistent changes in the proximal arm portions of the WMFT and the FM as well as in upper arm kinematics. Da Silva-Cameirão (2011) reported a similar response on the recovery of proximal movements in a pilot study using the Rehabilitation Gaming system in the acute phase post-stroke. This pattern of change was also noted in the kinematics of the movement. The changes in the distal clinical and kinematic measures were more varied with the exception of consistently robust changes in the maximum pinch force. The large changes in motor function, at least a portion of which will occur spontaneously, and the varied patterns of response in these subjects would suggest that large populations will be necessary to test hypotheses effectively in this population.

An important biomarker of functional recovery is the excitability of the corticospinal system (e.g., the integrity of the motor output) (Lazaridou et al, 2013; Qiu et al, 2011; Sampaio-Baptista et al, 2013). Transcranial magnetic stimulation (TMS) induced motor evoked potentials (MEP) are an established proxy of corticospinal excitability. The initial data in this feasibility study suggest that in the days following stroke, training and recovery may be associated with an expansion of the corticospinal network (area) and strengthening of corticospinal synaptic weights (volume). This said, testing corticospinal excitability using TMS in acutely ill patients can be challenging. Less than a third of our subjects (two of seven) were medically appropriate for TMS and consented to participate. Based on our participation rate, studies planning to use TMS measures to test hypotheses in subjects with acute CVA will need to recruit from large pools of potential subjects.

In this feasibility study we have shown that providing an intensive robotic/VR intervention in the early phases post-stroke and integrating it with on-going usual care rehabilitation is a definite possibility. There are multiple challenges to this type of intervention, the inherent heterogeneity of stroke, the variation in the time course of spontaneous recovery and the confounding effect of neural restitution and compensatory functional movements. Improvements in motor performance are probably the result of several processes that occur in parallel to each other. We propose that our battery of clinical, kinematic and neurophysiological measures might be able to provide a window into the overlapping processes and help to sort out the confounding issues in the recovery of upper extremity function post-stroke.

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Quantifying cognitive-motor interference in virtual reality training after stroke: the role of interfaces

A Vourvopoulos[1], A L Faria[2], M S Cameirão[3], S Bermúdez i Badia[4]

[1-4]Madeira Interactive Technologies Institute, Universidade da Madeira (UMa)
Funchal, PORTUGAL

[1,3,4]Centro de Ciências Exatas e da Engenharia, Universidade da Madeira (UMa)
Funchal, PORTUGAL

[2]Faculdade de Psicologia e de Ciências da Educação, Universidade de Coimbra
Coimbra, PORTUGAL

athanasios.vourvopoulos@m-iti.org

ABSTRACT

Globally, stroke is the second leading cause of death above the age of 60 years, with the actual number of strokes to increase because of the ageing population. Stroke results into chronic conditions, loss of independence, affecting both the families of stroke survivors but also public health systems. Virtual Reality (VR) for rehabilitation is considered a novel and effective low-cost approach to re-train motor and cognitive function through strictly defined training tasks in a safe simulated environment. However, little is known about how the choice of VR interfacing technology affects motor and cognitive performance, or what the most cost-effective rehabilitation approach for patients with different prognostics is. In this paper we assessed the effect of four different interfaces in the training of the motor and cognitive domains within a VR neurorehabilitation task. In this study we have evaluated the effect of training using 2-dimensional and 3-dimensional as well as traditional and natural user interfaces with both stroke survivors and healthy participants. Results indicate that 3-dimensional interfaces contribute towards better results in the motor domain at the cost of lower performance in the cognitive domain, suggesting the use 2-dimensional natural user interfaces as a trade-off. Our results provide useful pointers for future directions towards a cost-effective and meaningful interaction in virtual rehabilitation tasks in both motor and cognitive domains.

1. INTRODUCTION

Cerebrovascular accidents (CVA) or strokes are caused by disruption of the blood supply to the brain, resulting from either blockage (ischaemic stroke) or rupture of a blood vessel (haemorrhagic stroke) (MacKay and Mensah, 2004). Every year about 16 million new strokes are recorded worldwide (Strong, Mathers, and Bonita, 2007), making stroke one of the main causes of adult disability and it is expected to be one of the main contributors to the burden of disease in 2030 (WHO, 2008). Consequently, many stroke survivors suffer chronic conditions that require continuous treatment and rehabilitation, reducing their independence for basic everyday activity tasks, with a significant psychosocial and financial burden on patients, relatives and healthcare systems (Vincent et al, 2007). Therefore, with an estimated cost of 102 billion $ annual cost in the EU and USA combined (Di Carlo, 2009), a pressing need to find solutions that can help alleviating this situation is present.

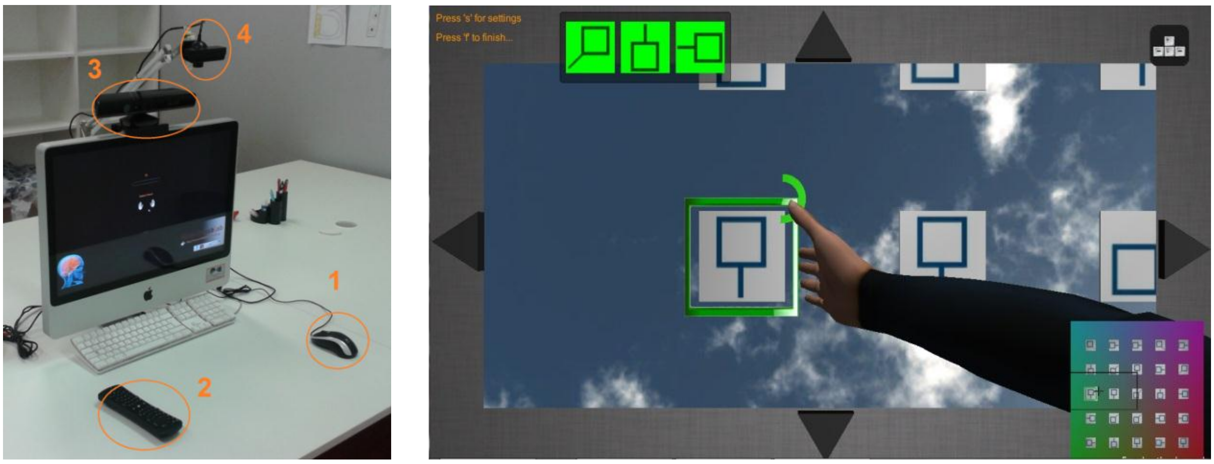
Recovery after stroke is slow, and the impact of current rehabilitation approaches mostly depends on the availability of highly trained health professionals, and access to the training frequency, intensity and duration that are needed. Unfortunately, public healthcare systems cannot always provide patients with the ideal long-term rehabilitation that is necessary. Virtual Reality (VR) for rehabilitation is an approach that provides novel solutions that can contribute towards low-cost and long-term rehabilitation (Bermudez i Badia and Cameirao, 2012) as well as support the requirements for an effective training. Through VR, researchers design fully controlled environments with specifically designed for different diagnostics and motivate patients through personalised tasks and feedback (Lucca, 2009). Besides immersive or non-immersive VR based rehabilitation systems, Serious Games have been used for training (Alankus, Lazar, May, and Kelleher, 2010; Burke et al, 2009), capitalising in motivational factors that are essential for recovery (Maclean, Pound, Wolfe, and Rudd, 2000). In addition, these novel approaches to rehabilitation not only allow for the individualization of training and monitoring by physicians, but also enable patients to play a more active role in their rehabilitation process by self-monitoring their own improvements in their private space. In fact, VR training for stroke survivors has been assessed in the past with encouraging results (Broeren, Rydmark, Björkdahl, and Sunnerhagen, 2007; Cameirão, Badia, Duarte, Frisoli, and Verschure, 2012). Further, a recent Cochrane review included 19 of the latest studies with a total of 565 participants for comparing the impact of VR (Laver, George, Thomas, Deutsch, and Crotty, 2012). Through this meta-analysis can be found that VR is more effective in the retraining of activities for daily living (ADL) compared to traditional methods. Unfortunately, accessibility to these therapies remains a challenge especially for patients with severe disability and worse predicted outcome.

In order to tackle the accessibility limitation of VR systems, approaches such as the RehabNet (Vourvopoulos, Faria, Cameirao, and Bermudez i Badia, 2013) aim at broadening modern VR rehabilitation approaches to include patients with different prognostic (motor and cognitive) and provide low cost at-home rehabilitation solutions for all. The RehabNet framework and methodology is based on improving: (1) accessibility of patients to the treatment through different interfaces; (2) patient compliance with therapy with the use of VR and Serious Games; (3) understanding of the technological and neuroscientific underlying mechanisms that affect therapy's effectiveness. However, the role and the effects of the type of interface in VR systems for neurorehabilitation are unclear with no previous literature to support the relationship between cognitive profile and type of interface. In fact, a recent review with an emphasis on evidence of VR technologies' efficacy rises concerns about the benefits of sophisticated technology for upper limb rehabilitation (Fluet and Deutsch, 2013). Thus, the specific benefits over conventional therapy of approaches such as robots, immersive vs. non-immersive VR, and 2D vs. 3D still remain unclear. Here we address the effect of different interfaces for VR interaction in a virtual task for rehabilitation combining cognitive and upper limb motor re-training. This research attempts to identify and understand the effect of different types of low-cost interfaces in both cognitive and motor performance in a VR task. We specifically address the effect of the nature of the interface (traditional interface vs. natural user interface), and the effect of dimensionality (2D movement on a table surface vs. 3D movement without arm support). In this paper we present preliminary data of an ongoing comparative study with healthy participants and stroke survivors using the RehabNet approach.

2. METHODOLOGY

2.1 Virtual Reality Motor and Cognitive Dual Training Task

RehabNet, a toolset developed for motor and cognitive neurorehabilitation, was used for implementing a dual motor and cognitive training task in both a clinical and non-clinical environment (Vourvopoulos et al, 2013). The software suite is composed by a Control Panel (RehabNetCP) that integrates a large number of commercial and experimental interface devices to enable the patient-task interaction within VR.



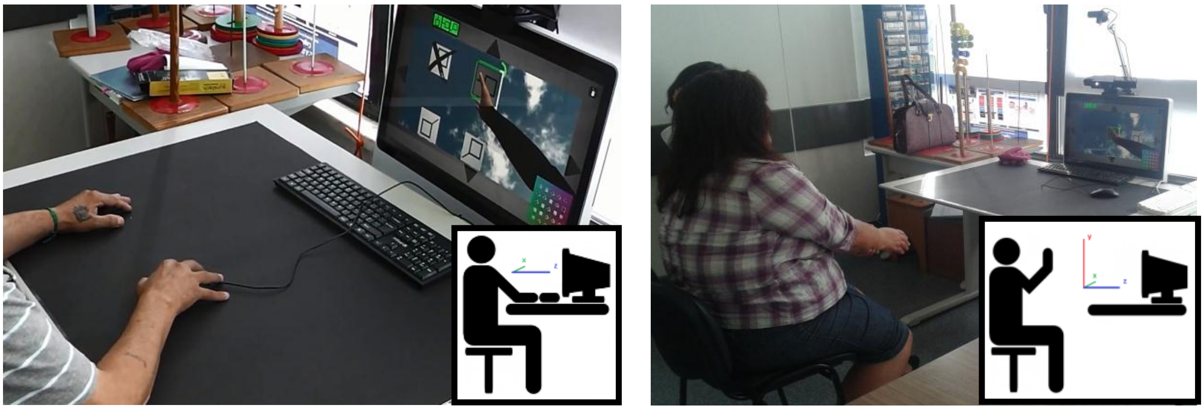
(a) *(b)*

Figure 1. *Virtual-reality motor and cognitive dual-training task. (a) Experimental setup including the (1) mouse, (2) Airmouse, (3) Kinect, (4) camera interface technologies. (b) VR Toulouse-Piéron task. The virtual environment shows a representation of an arm with an active timer over a selected tile.*

The dual VR task was inspired by a well-established cancelation task, the Toulouse-Piéron task (Toulouse, Piéron, and Pando, 2004), in the following referred as TP-VR. The VR implementation includes a first person virtual representation of the paretic arm, which is controlled via the RehabNetCP through various interfaces (see Figure 1a). The virtual environment is composed by a grid of 25 tiles with different symbols, navigation arrows at the edge of the screen, a mini-map, and 3 target elements (out of a total of 9) in green (see Figure 1 b). By means of physical movements and the use of different interface technologies, users can control the position of the virtual paretic arm on the screen. The selection of each tile is performed with the use of a timer while the virtual arm is hovering over. Consistent with the original Toulouse-Piéron task, the score is calculated with the following formula:

$$\textit{Score} = \textit{Correct} - (\textit{Wrong} + \textit{Omissions})*100/\textit{TotalTiles} \tag{1}$$

In this experiment, we decided to explore the effect of the use of Traditional Interfaces (TI) vs. Natural User Interfaces (NUI's) in 2-dimensional and 3-dimensional work spaces (see Figure 2). As TI we selected a 2D and a 3D pointing devices (a mouse and the Airmouse respectively), and as NUI we selected 2D and 3D camera-based tracking technologies (AnTS and Kinect respectively). In order to personalise each user interface to the capabilities of the hemi-paretic arm of each patient, we developed a Range of Motion (RoM) calibration procedure. Hence, at the beginning of each session a calibration was taking place in order to adjust the game based on the patients' RoM. Conditions were randomised within the experimental sessions with each session including one interface only. Participants were not imposed any constraint in movement type or speed.



(a) *(b)*

Figure 2. *2-dimensional (a) and 3-dimensional (b) experimental setups. Inset images show the user's position relative to VR system and the allowed movements.*

2.2 Experimental Setup

The experimental setup was composed by a desktop computer (OS: Windows 7, CPU: Intel core 2 duo E8235 at 2.80GHz, RAM: 4Gb, Graphics: ATI mobility Radeon HD 2600 XT), running both the RehabNetCP and the TP-VR training task. The available interfaces for this assessment included a standard mouse (TI-2D), an RC11 Airmouse (TI-3D) (Measy Electronics Co., Ltd, China), a PlayStation Eye camera (Sony Computer Entertainment Inc., Tokyo, Japan) combined with the Analysis and Tracking System (AnTS) for the tracking of a coloured glove (NUI-2D) (Mathews, Badia, and Verschure, 2007), and Kinect (NUI-3D) (Microsoft Corporation, Washington, USA). A standard keyboard was also used for baseline measurements. Data acquisition, filtering, logging were performed by the RehabNetCP and sent to the virtual environment via a UDP network connection. The virtual environment was developed using the Unity 3D game engine (Unity Technologies, San Francisco, USA). For all conditions regardless of the interface being used, the Kinect skeletal tracking was also used to assess user's kinematics. Thus, Kinect provided us with rich kinematic data for all interfaces for later comparison. The procedure was transparent from the participants' point of view and they were only required to use the different interfaces for crossing out targets on screen. For each session, the in-game data and user movement kinematics were stored for later analysis.

2.3 Participants

We performed a preliminary study consisting of a total sample of 66 training sessions from nine participants, three stroke survivors (1 male, 2 female), (age mean = 54, std = 15) and six healthy users (4 male, 2 female), (age mean = 30, std = 5.6). During a period of 1 month, each patient was exposed to an average of 12 training sessions with different interfaces, and healthy participants to 5 training sessions in one day. The clinical scales to determine the level of cognitive severity included (Table 2): The Addenbrooke Cognitive Examination - Revised

(ACE-R) (Mioshi, Dawson, Mitchell, Arnold, and Hodges, 2006) (Firmino, Simões, Pinho, Cerejeira, and Martins, 2008), covering a wide range of cognitive impairments incorporating five subscales (attention, memory, verbal fluency, language and visuo-spatial capability). The clinical scales to determine the level of motor severity of the hemi-paretic arm included: the Fugl-Meyer assessment, the Barthel Index. The Fugl-Meyer assessment adapted to evaluate the upper-limb (Gladstone, Danells, and Black, 2002). Stroke patients were selected at the Physical Medicine and Rehabilitation Department of Nélio Mendonça Hospital (Funchal, Portugal) according to the following criteria: ischemic stroke; at least 2 years of schooling; stroke event with less than a year; arm hemiparesis; no hemi-spatial neglect; sufficient cognitive ability in order to understand the training task instructions, as assessed by the MMSE ≥ 15 included in the ACE-R; 45 to 85 years old and motivation to participate in the study. The six healthy participants were students and staff from the University of Madeira and were recruited at the Madeira Interactive Technologies Institute. This study was approved by the ethics committee of the Health Service of Madeira Autonomous Region and all patients signed an informed consent form.

Table 1. *Patient profile for Cognitive, Motor and Activities of Daily Living.*

		Patient 1	Patient 2	Patient 3
ACE-R	Total	78	93	57
	Attention	18	18	16
	Memory	18	25	11
	Verbal Fluency	7	11	6
	Language	25	23	13
	Visuo-Spatial	10	16	11
Fugl-Meyer	Upper-Limbs	50	24	48
	Sensibility	8	7	12
	Passive Movement	24	20	23
	Pain	24	16	22
ADL's	Barthel	80	85	80

3. RESULTS

Data from 66 training sessions were gathered. Kinematics (captured through Kinect) and game data (task events in TP-VR) were synchronously logged to an XML file and parsed to Matlab (MathWorks Inc., Massachusetts, US) for analysis after each session. Kinematic data were initially cleaned from artefacts. Positional data were smoothed through Gaussian filtering window (60 seconds length, SD = 5) and the average velocity (m/s), acceleration (m/s^2), RoM (cm^2), and Smoothness Index (SI) (number of acceleration minima) was calculated. The in-game data of the TP-VR task included the overall scoring (in %, equation 1), the task duration (in seconds), and number of mistakes. These data provided information of the patient's behaviour within the VR environment together with the acquired movement kinematics.

3.1 Motor Domain

Figure 3 illustrates the data for both healthy and stroke participants in the motor domain (kinematic information). It can be observed that the average velocity of the patients' movements does not display differences among interfaces except for AnTS (NUI-2D), which is twice faster (0.043 m/s) compared to both 3D interfaces at (~0.020 m/s) (Figure 3a,i). For healthy participants there were clear differences based on the interface, being 2D interfaces slower than 3D (Figure 3 b,i). However, movement velocities achieved with both 3D interfaces (Airmouse and Kinect) are comparable. No differences can be observed for movement acceleration, neither patients nor healthy participants (Figure 3 ii).

As for movement smoothness, patient data shows higher SI (the higher the SI count the less smoother the movement) for 2D than for 3D interfaces (Figure 3a,iii). However, a different trend is observed for healthy participants, showing smoother movements for NUI than for TI (Figure 3b,iii). Finally, for RoM there is a clear distinction between the 2D vs. 3D interfaces for both patients and healthy participants (Figure 3,iv). In this case, 3D interfaces push participants towards wider movements that can go up to 1m larger than 2D movements.

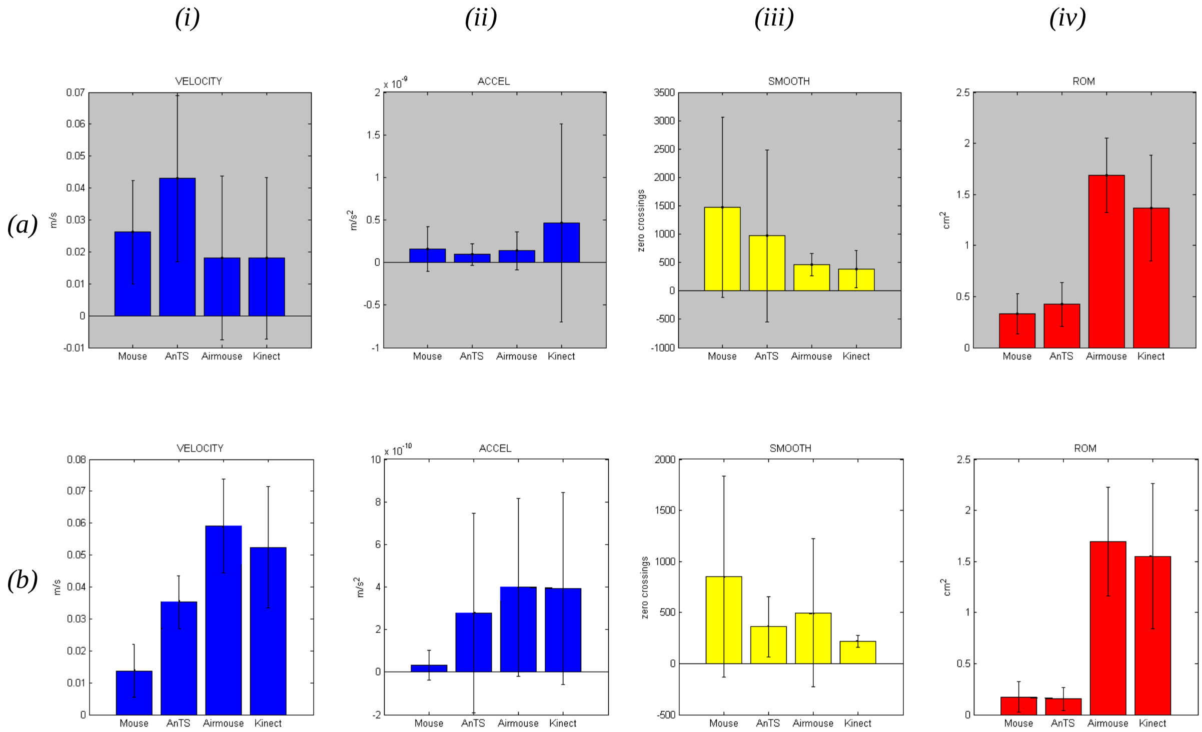


Figure 3. *Motor domain bar-plots for (i) Velocity, (ii) Acceleration, (iii) Smoothness Index and (iv) Range of Movement (RoM) from (a) patients and (b) healthy participants. Bar height indicates mean value, and the whiskers indicate standard deviation.*

3.2 Cognitive Domain

Figure 4 illustrates the data in the cognitive domain for both stroke patients and healthy participants for all four tested interfaces plus the keyboard. In the case of patients, the task score is higher for both 2D interfaces (mouse and AnTS with a mean score of 64.9% and 62.2% respectively) whereas scores with 3D interfaces is close to 0% or even negative, that is, more mistakes than correct answers (Figure 4 a,i). Task scores for healthy participants are higher than those of patients, being NUI interfaces better compared to TI (Figure 4 b,i). When we analyse the time for task completion we can see that there is a clearer trend for patients than for healthy participants (Figure 4 ii). For patients longer times can be found for baseline (keyboard) and 2D interfaces, being shorter towards the 3D interfaces with Kinect being the fastest. Finally, it can be seen that patients perform more mistakes when using the keyboard and the Kinect than for the remaining interfaces (Figure 4 a,iii). Instead, for healthy participants it can be observed that the least mistakes were on the 3D interfaces (Figure 4 b,iii).

3.3 Interface Comparison

In order to be able to combine all motor and cognitive performance measures into a comparative analysis we ranked (between 1-4 for motor and 1-5 for cognitive, being higher a better outcome) the previously presented results (Table 2). Thus, based on the nature of the interface (TI vs. NUI and 2D vs. 3D) we can quantify their contribution towards objective cognitive and motor performance metrics. For example, in the motor domain higher velocity, larger RoM, and smoother movement (lower SI) are desirable. Likewise, higher scores, shorter completion times and fewer mistakes are preferable in the cognitive domain.

The ranking analysis in the motor domain shows that for patients 3D interfaces are preferable in terms of acceleration, smoothness, and RoM, whereas with 2D interfaces we find the fastest movements (Table 2a, motor). As a result the Kinect is the best globally ranked interface (rank sum = 13). For healthy participants we find that 3D interfaces systematically provide the best motor outcomes, being the Airmouse and Kinect ranked the best with a rank sum of 14 and 13 respectively (Table 2b, motor). In the cognitive domain there is no clear interface outperforming the others in all metrics. 2D interfaces provide the best task scores but also the slowest task completion times (Table 2a, cognitive). In the case of healthy participants, there is a clear preference in the cognitive domain towards NUI (either 2D or 3D), providing both a rank sum of 12 (Table 2b, cognitive).

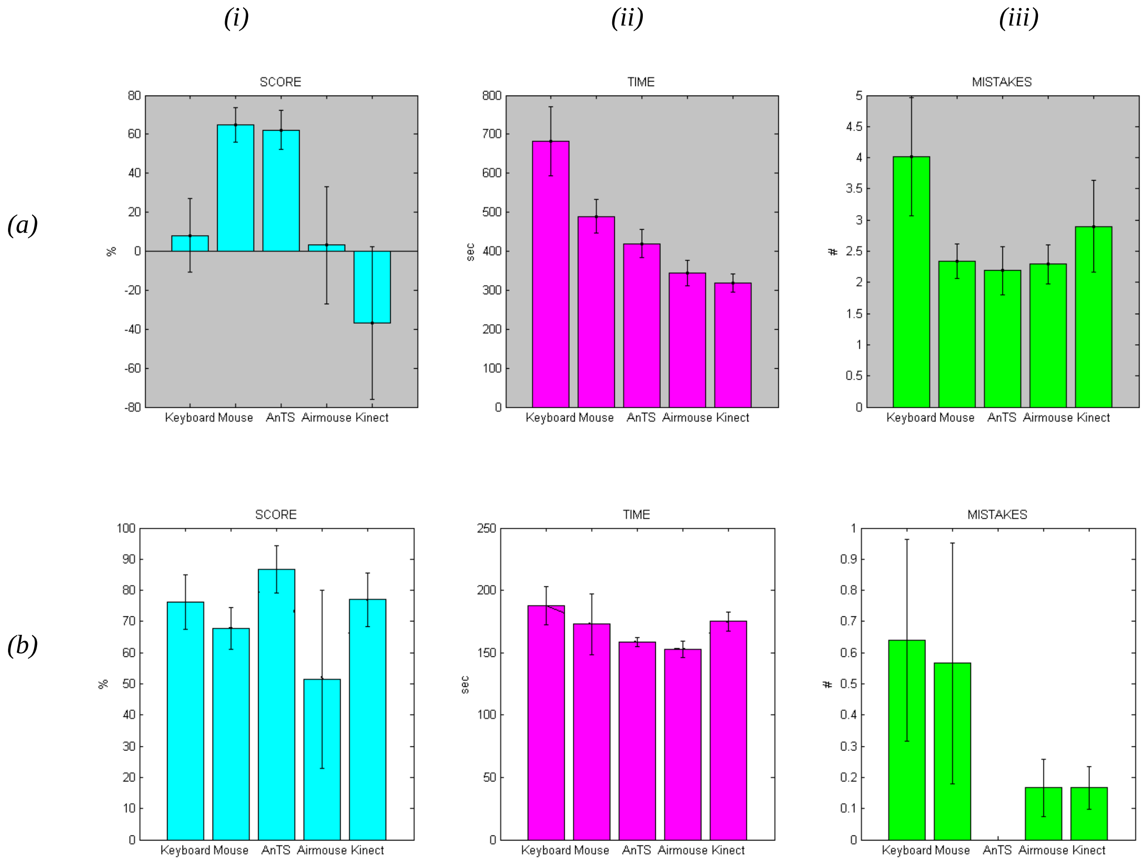


Figure 4.*Cognitive domain bar-plots for (i) Score, (ii) Time, and (iii) Mistakes from (a) patients and (b) healthy participants. Bar height indicates mean value, and the whiskers indicate standard deviation.*

Table 2. *Ranking of interfaces according to motor and cognitive performance metrics from (a) patient and (b) healthy data. The higher the ranking the better performance.*

		(a) Patients					(b) Healthy				
			2D		3D			2D		3D	
		Keyboard	Mouse	AnTS (NUI)	Airmouse	Kinect (NUI)	Keyboard	Mouse	AnTS (NUI)	Airmouse	Kinect (NUI)
Motor	Velocity		3	4	1	2		1	2	4	3
	Acceleration		3	2	1	4		1	2	4	3
	Smoothness		1	2	3	4		1	3	2	4
	RoM		1	2	4	3		2	1	4	3
Total			8	10	9	13		5	8	14	13
Cognitive	Score	3	5	4	2	1	3	2	5	1	4
	Time	1	2	3	4	5	5	3	2	1	4
	Mistakes	5	3	1	2	4	1	2	5	4	4
Total		9	10	9	9	10	9	7	12	6	12

3.4 Multi-linear Regression Data Modelling

Following the above qualitative analysis, a more quantitative approach is necessary to understand better the impact of our experimental variables on the motor and cognitive domains. We decided to use a stepwise multi-linear regression modelling approach for detecting and quantifying the effect of the experimental independent variables on the dependent ones. Our independent variables include interface, TI or NUI, and user demographics (user type, gender, age). The dependent variables in the motor domain include velocity, acceleration, range of movement, and smoothness; and in the cognitive domain include score, time to completion and number of mistakes.

Table 3. *Multi-linear stepwise regression model. The table shows the coefficients of the independent variables that have a significant contribution in the regression model for all metrics in the motor and cognitive domains and the R square values.*

		User Type	Gender	Age	Interface	Interface Type	Dimension	R-Sq
Motor	Velocity						0.0295	0.52
	Acceleration	-1.58E-10						0.14
	Smoothness				-368.579			0.19
	RoM						1.5366	0.77
Cognitive	Score	16.3564						0.11
	Time	-114.5528						0.59
	Mistakes	-1.3194					-0.345	0.92

Table 3 summarises the modelling findings. In the motor domain we find that the dimension of the interface has a significant contribution towards determining the velocity of the movement (*Coeff. = 0.029, p<0.001*). 3D interfaces generate faster movements, probably due to the fact that 3D movements are more ballistic in comparison to movements on a surface. The acceleration of upper limb movements is significantly affected by the type of the user (*Coeff. = -1.58e-10 , p<0.05*), were healthy participants have higher acceleration values than patients. The smoothness of movement is significantly affected by the choice interface (*Coeff. = -368.58, p<0.05*). In this case, 3D interfaces contribute towards smoother movements. Finally, the dimensionality of the interfaces (2D vs. 3D) significantly contributes to the RoM (*Coeff. =1.54, p<0.001*). In the cognitive domain, for all dependent variables we find a significant contribution of the user type (patient vs. healthy participant): score (*Coeff. =16.36, p<0.05*), time (*Coeff. = -114.55, p<0.001*), and mistakes (*Coeff. = -1.32, p<0.001*). It can be seen that healthy participants perform better and resolve the task faster and with less mistakes. Finally, we find a significant contribution of the dimensionality of the interface (2D vs. 3D) in the number of mistakes (*Coeff. = -0.34, p< 0.001*), performing less mistakes with 3D interfaces.

4. CONCLUSIONS

This research aims towards the development of VR technologies for the inclusion of all patients into VR neurorehabilitation therapy, accommodating both software and hardware aspects of the technology. In this project, both stroke survivors and healthy participants have used four different computer interfaces for virtual environment interaction in order to gather insights on how the choice of interface in a neurorehabilitation task affects outcomes in the motor and cognitive domains.

Our results indicate that patients perform faster upper limb movements by using 2D interfaces whereas healthy participants are faster by using 3D. This can be an indication that patients can interact faster when they support the paretic arm on a surface rather moving it within the 3D space, and as a result, promoting a more stable way for interaction. Consistently for patients and healthy participants, 3D interfaces contributed towards smoother movements as quantified by the Smoothness Index (SI). This could indicate that 3D interfaces generate smoother movements because there is no friction with a surface that may affect the quality of the movement. Finally for RoM, 3D interfaces seem to contribute towards the exploitation of movements in a larger space than 2D interfaces. However, overall NUI render better motor performance. Consequently, depending on the specific desired outcomes from training, a 2D-3D or TI-NUI interface may be preferred. In the cognitive domain, we found that better scores come at the expense of longer completion times, and shorter completion times at the expense of mistakes. Our findings verify the observed situation where the patients get tired faster when using a 3D interface, leading to faster termination of the session. Furthermore, traditional interfaces contribute towards better scoring but at the expense of poor motor performance. Consequently, the challenge is in identifying the best trade-off between the two domains in order to provide each patient with the best possible rehabilitation solution, taking into account their specific motor and cognitive re-training needs. Thus, AnTS, a 2D-NUI interface, seems to be the preferred compromise for patients.

The large variability in cognitive function of the participants as assessed by the ACE-R, may have been the cause behind the lower accuracy of the score variable in the multi-linear regression model. However, this variability did not compromise the accuracy of the other models in the cognitive domain such as time or mistakes. Another possible limitation of the study is an eventual learning effect during the 4 week/12 sessions experimental period. Since no intermediate evaluation took place, this was minimized by randomizing the exposure to the interfaces. Finally, despite the small sample size of this pilot experiment, we believe that such a quantitative approach can provide useful pointers towards the design and deployment of future VR and rehabilitation systems taking into account both cognitive and motor domains.

In this pilot study we introduced a novel approach towards virtual rehabilitation to identify the particular benefits of interfaces and their characteristics on cognitive and motor performance. The ultimate goal of the RehabNet approach is to widen the spectrum of patients that can benefit from virtual rehabilitation, for in-home or clinical environments. Current target is to extend this study to gather data from more stroke survivors and also extend the analysis to include motor and cognitive clinical evaluations. This may allow us to find correlates between clinical evaluations and motor and training outcomes that will enable us to derive general and yet specific guidelines for the selection of interfaces in virtual neurorehabilitation. In the future we aim to extend the RehabNet to incorporate brain-computer interfaces to enable motor and cognitive training in patients with very low or no mobility.

Acknowledgements: This work is supported by the European Commission through the RehabNet project - Neuroscience Based Interactive Systems for Motor Rehabilitation - EC (303891 RehabNet FP7-PEOPLE-2011-CIG), and by the Fundação para a Ciência e Tecnologia (Portuguese Foundation for Science and Technology) through SFRH/BPD/84313/2012, SFRH/BD/97117/2013 and Projeto Estratégico - LA 9 - 2013-2014 (http://neurorehabilitation.m-iti.org).

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Cognitive stimulation through mHealth-based program for patients with Alcohol Dependence Syndrome – a randomized controlled study

P Gamito[1], J Oliveira[1], P Lopes[1,2], R Brito[1], D Morais[1], S Rebelo[2], D Silva[2], C Caçôete[2], A Deus[2]

[1]COPELABS/Lusophone University
[1]EPCV/Lusophone University
Campo Grande, 376, 1749-024 Lisbon, PORTUGAL

[2]Novo Rumo Clinic. São João de Deus Institute,
Estrada do Telhal, Mem Martins, Sintra, PORTUGAL

{pedro.gamito, jorge.oliveira, diogo.morais}@ulusofona.pt,
{pjflopes, rodrigoreisbrito, sararebelo03, didifipaa, cristiana.cacoete}@gmail.com, alberto.deus@isjd.pt

[1]*labpsicom.ulusofona.pt*

ABSTRACT

Alcohol abuse can impact on general cognitive functioning and more particularly on frontal lobe functions. One option available to reduce this impact may rest on rehabilitation paradigms that include cognitive stimulation programmes. This paper reports on a randomized controlled study where two sample of patients with alcohol dependence syndrome where enrolled: 1) on a mHealth-based cognitive stimulation program (CSP) within alcohol dependence treatment (experimental group) and 2) on the alcohol dependence treatment without CSP (control group). The CSP mHealth applications consisted on a serial of serious games designed to stimulate frontal lobe functions. Assessment was conducted with the Mini-Mental State Examination and the Frontal Assessment Battery. After 10 stimulation sessions the experimental group evidenced a significant improvement on frontal-lobe functioning when compared with the control group. As expected, no differences on general cognitive functioning were found between groups.

1. INTRODUCTION

Alcohol abuse has been associated with significant morphological changes in the brain. Structural neuroimaging studies have shown that changes affect several areas of the grey matter and the white matter, with cortical atrophy and reductions of brain volume (Bjork et al, 2003; Gazdzinski et al, 2005; Sullivan et al, 2005). These changes are found frequently in the frontal lobes (Moselhy et al, 2001; De Bellis et al, 2005; Kubota et al, 2001), in particular in the parietal and temporal cortex and in the white matter adjacent to these regions (Sullivan et al, 1995, 1996), as well as in the hippocampus, in the basal ganglions, in the thalamus and in the cerebellum (Sullivan and Pfefferbaum, 2005; De Bellis et al, 2005) and in the corpus callosum (Schulte et al, 2005; Pfefferbaum et al, 2006). These changes – and in particular those of the frontal white and grey matter – are associated to the severity of alcohol consumption (Pfefferbaum et al, 1998; De Bruin et al, 2005; Cardenas et al, 2005; De Bellis et al, 2005; Gazdzinski et al, 2005). In fact, several studies have shown that alcohol-dependent patients exhibit enlarged brain ventricles and sulcus along with smaller white and grey matter. The increase in the cerebrospinal fluid and reduction of the corpus callosum, as well as changes in the prefrontal and orbitofrontal areas are associated with the duration of alcohol abuse, even after longer periods of abstinence post-alcohol abuse (Bechara et al, 2001; Kaufman and Levin, 2001).

These changes have a functional impact: they are associated to significant changes in the cerebral metabolism of the prefrontal cortex, as has been shown in studies using Positron Emission Tomography (PET) and Single Photon Emission Computed Tomography (SPECT) (Adams et al, 1993, 1995; Volkow et al, 1997; Tutus et al, 1998; Gansler et al, 2000). Regarding neurotransmission, a more recent study using PET and addiction-specific GABA receptors showed reductions in the amount of neurotransmitters among alcohol addicts (Lingford-Hughes et al, 2005).

The consequences of these changes at the cognitive level have been shown also in a variety of studies, which indicate changes in visual-spatial abilities, psychomotor speed and frontal lobe functioning, particularly in executive functions that comprise several cognitive domains raging from working memory, attention, planning to decision-making and inhibitory control (Chan et al, 2008; Parsons, 1998; Sullivan et al, 2000). These changes in alcohol addicts are reflected at the level of learning, attention, long and short-term memory, abstraction, problem resolution, efficacy in information processing (Noel et al, 2005) and decision-making (Bechara et al, 2001).

On the other hand, abstinence from alcohol has been associated to important recovery in brain volume, which grows with length of abstinence periods, in particular during the first few months after alcohol consumption stops (Moselhy et al, 2001).

The effect of abstinence can be leveraged and enhanced by cognitive stimulation programmes (CSPs). For example, Yohman and colleagues (1988) compared the performance on neuropsychological tests of a) recovering alcoholics who engaged in twelve hours of memory stimulation exercises spread out over two weeks b) recovering alcoholics who engaged in problem resolution techniques with a similar schedule, c) recovering alcoholics who did not engage in any stimulation over two weeks, d) and a control group of non-alcoholics. All the recovering alcoholics groups performed worse than the non-alcoholics but, importantly, the recovering alcoholics performed better after participating in the two cognitive stimulation programmes tested. Goldstein and colleagues (2005) tested the efficacy of a five-session CSP programme with alcoholics in detox, and found improved performance on a battery of neuropsychological tests among participants who participated in the sessions, in contrast to controls.

Traditionally, CSP programmes are based on pencil-and-paper exercises. More recently, some researchers have been adopting computer-based interactive serious games (SGs) to increase motivation and adherence to the programmes (Edmans et al, 2007; Gamito et al, 2011). In particular, these CSPs have been tested on patients recovering from alcohol or substance-abuse (Fals-Stewart and Lam, 2010; Gamito et al, 2013; Grohman and Fals-Stewart, 2003). A study of Gamito and colleagues (2013) was conducted with the aim of comparing the efficacy on recovering the cognitive function of alcoholics in traditional pencil-and-paper CSP with that of a mobile device-based CSP based on the same exercises. Their preliminary data indicate that although there was a general trend for improvement (in particular in mental flexibility, attention, and visual-spatial capacity) in all groups, which can be attributed to abstinence, this effect was more pronounced in the mobile-based CSP group.

In the current study, we again assessed the efficacy of a mobile device-based CSP for the cognitive rehabilitation of recovering alcoholics. We focused on comparing its efficacy on the recovery of specific frontal lobe-based functions with that of general cognitive abilities. Because our CSP exercises follow the general standard for these exercises, which are based mostly on training attention, working memory, logical reasoning and attention, having been conceived initially for patients with acquired brain injuries, we expected that they would have a stronger impact on frontal lobe functioning than on general cognitive abilities.

2. METHOD

2.1 Sample

This study was based on a randomized controlled trial (RCT) design to test the effects of neuropsychological intervention through mHealth-based applications in patients with alcohol dependence syndrome. The required sample size was calculated *a priori* with Cohen's f effect size for F tests (Cohen, 1988). A total sample size of 40 patients was required for this trial in order to detect a medium effect size (.30; $1\text{-}\beta = .80$; $\alpha = .05$). The assignment of patients to each condition was performed using simple randomization. Figure 1 describes the flow of the participants between conditions.

Forty-two patients diagnosed with alcohol dependence syndrome (ADS) according to DSM-IV criteria (38 males, M*age* = 45.45 years, SD*age* = 10.31, 9 years of formal education, M = 9, SD = 3.72) were recruited upon entry into an alcohol rehabilitation programme at a private clinic consisting of a traditional medication-aided abstinence treatment with psychological assistance.

Only patients that scored higher than the cut-off values for their age on the Mini Mental Examination Test – MMSE (Folstein et al, 1975) and with no clinical scores on the Symptoms Checklist Revised - SCL-90-R (Derogatis, 1994) were included in the study. Patients continued their regular medication regimen consisting of anxiolytics, mostly Diazepam and Tiapride, which help minimize withdrawal symptoms, and vitamins. The assistant psychiatrist of each patient guaranteed the stability of the medication regimens throughout the program.

Patients with dependency from substances other than alcohol or with history of previous neurological disorders were excluded from the study. Patients were also screened for minimal computer literacy; no patients were excluded due to these criteria.

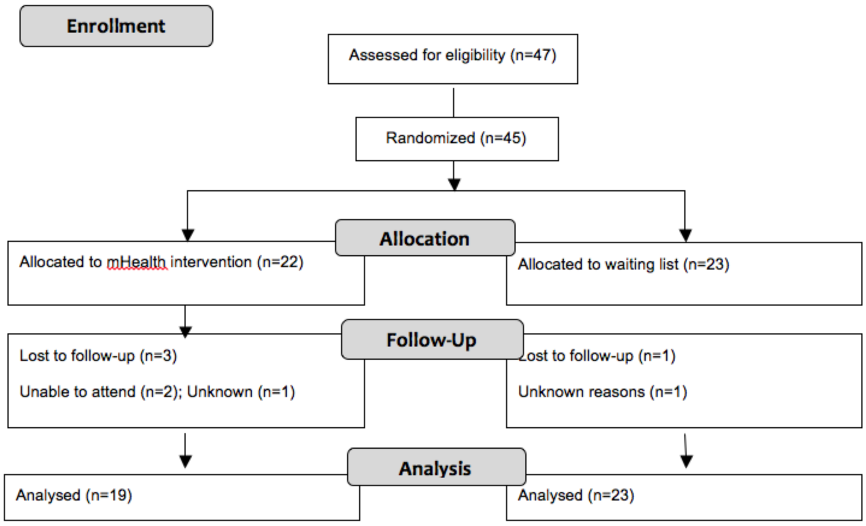

Figure 1. *Flow of the participants throughout the protocol.*

2.2 Measures

The following day after the first assessment, patients were tested on the first batch of a battery of neuropsychological tests and on the fourth day on the remainder of the battery. They were re-tested on the full battery at the end of the trial, a month later. For the current study we will focus only on two tests: the Mini-Mental State Examination (MMSE; Folstein et al, 1975) which measures general cognitive ability, and the Frontal Assessment Battery (FAB; Dubois, et al, 2000), which measures frontal-lobe functions.

2.3 Procedures

After the first testing, a randomly selected waiting list control group (n = 23, 22 males, M*age* = 48.61 years, SD*age* = 8.02, years of formal education, M = 9, SD = 3.68) simply continued following the traditional alcohol rehabilitation programme, a trial group (n = 19, 16 males and 3 females, Mage = 41.62yrs, SD*age* = 11.64, years of education, M = 8, SD = 3.84) also participated in a cognitive stimulation programme (CSPs) consisting of ten 45-50min sessions, twice or thrice a week for a month, starting from the sixth day of treatment, in which they played several serious games developed for Android and Windows (some of which were developed by this team, whilst others are available commercially) designed to stimulate in particular attention, memory and decision making, but also language, processing speed, strategic planning, perception, and spatial vision. At the end of the month of treatment all patients were re-tested on the full battery of neuropsychological tests. Prior to the initial screening, patients gave their written informed consent to the intervention. This trial was approved by the ethics committee of the host research institution.

The mobile cognitive stimulation program consisted of several mobile applications that were developed according to traditional paper-and-pencil rationales and originally conceived for cognitive stimulation on patients that had acquired cognitive impairments independently of the cause. Cognitive stimulation in each session comprised attention, working memory and logical reasoning exercises, which were standardized for all the patients in cognitive stimulation (see Table 1 for a more detailed description). The level of difficulty of each task increased progressively (i.e., one level at a time between sessions) throughout the cognitive stimulation rationale. In the last session, the same neuropsychological tests used in the first assessment were again applied. Two different teams of therapists were involved in recruitment, assessment and cognitive stimulation. A first group of therapists conducted patients' recruitment and assessments at baseline and follow-up. In the cognitive simulation sessions, an independent team of therapists provided the mobile devices with the exercises and supervised the sessions.

The hardware used to perform the exercises consisted of Samsung Galaxy 10.1" tablets. The applications (example shown in Figure 2) were developed using Unity 2.5 (Unity Technologies TM), and their alpha and beta versions had been previously tested by a group of students.

Table 1. *Cognitive Stimulation Program – Sessions and m-Health applications.*

Session1. Slot[4)]/Memory[5)]/Parking Zone[7)]/Under pressure[8)]/Snowflakes[2)]
Session2. Slot[4)]/Memory[5)]/Under pressure[8)]/Snowflakes[2)]/Right order[3)]
Session3. Slot[4)]/Memory[5)]/Hanoi Tower[6)]/Snowflakes[2)]/Right order[3)]
Session4. Slot[4)]/Memory[5)]Odd-even[3)]/Parking Zone[7)]/Snowflakes[2)]
Session5. Basket[3)]/Odd-even[3)]/Hand tricks[8)]/Brick[1)]/Memory[5)]
Session6. Hanoi Tower[6)]/Parking Zone[7)]/Under pressure[8)]/Memory[5)]/Snowflakes[2)]
Session7. Parking Zone[7)]/Under pressure[8)]/Selective transfer[4)]/Memory[5)]/Snowflakes[2)]
Session8. Selective transfer[4)]/Brick[1)]/Hand tricks[8)]/Memory[5)]
Session9. Parking Zone[7)]/Brick[1)]/Hand tricks[8)]/Memory[5)]
Session10. Slot[4)]/Memory[5)]/Parking Zone[7)]/Under pressure[8)]/Snowflakes[2)]

Note: Cognitive stimulation for [1)]perception; [2)]processing speed; [3)]reasoning; [4)]attention; [5)]memory; [6)]decision making; [7)]planning; [8)]spatial vision. These exercises are available online at (http://labpsicom.ulusofona.pt)

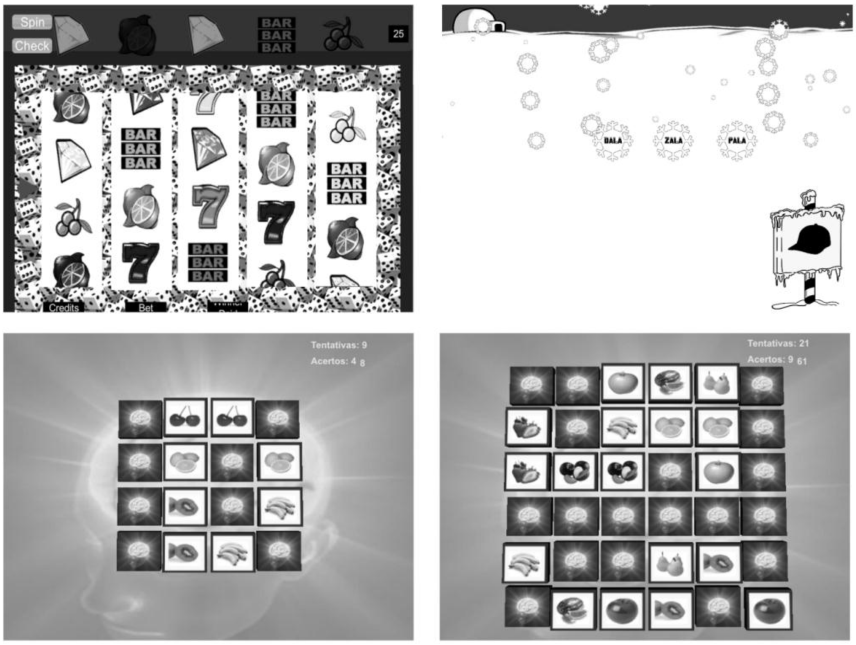

Figure 2. S*lot machine (top-left) for attention, visual memory task (bottom-left and bottom-right with increased difficulty) for working memory and the word-object correspondence (top-right) for logical reasoning.*

3. RESULTS

The dependent variables from the neuropsychological tests used for statistical analysis were the total scores of the MMSE and the FAB. The two groups did not differ in either gender or education, but given that there was a difference in age between groups (patients in the CPS group were significantly older than those in the waiting list control condition, $t(47) = 2.29$; $p = .027$), this variable was included as covariate in repeated measures Analysis of Covariance designs. Thus, two repeated measures ANCOVAs were performed for the total scores respectively of the MMSE and FAB with one within subjects' factor (baseline vs. follow-up), one between subjects' factor (i.e., group: m-Health cognitive stimulation vs. waiting list) and one covariate (i.e., age).

Results showed, as expected, no significant differences between groups on the MMSE, which measures general cognitive ability. The effects of age in this analysis were also non-significant ($p > .05$). On the other hand, the results of the FAB revealed a statistically significant interaction effect between factors ($F(1, 39) = 4.308$; $\eta 2 = .099$; $p = .045$). This simple effects analyses for each group of the difference between baseline and follow-up showed that only the improvement in patients exposed to m-Health intervention was statistically significant (F(1, 39) = 13.500; η2 = .257; p = .001), indicating an improvement in frontal lobe functions following the m-Health intervention with virtual exercises, but not in the control group (Figure 3). No significant effects of the covariate were found in this analysis (p > .05).

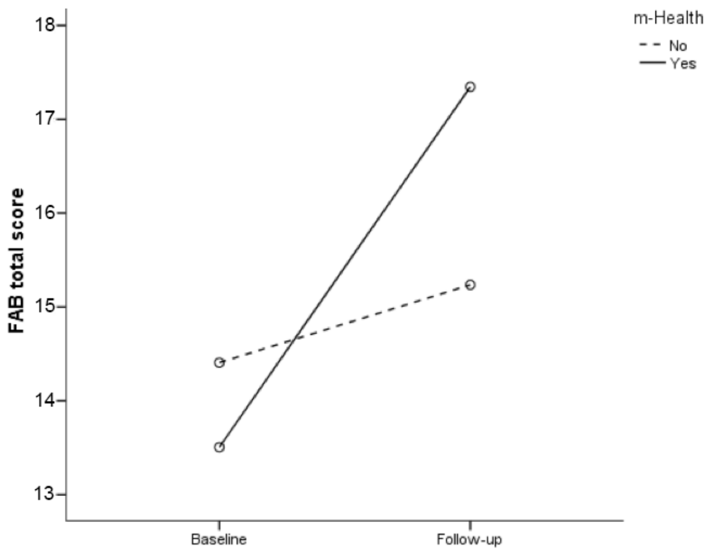

Figure 3. *Improvements in FAB scores at follow-up for m-Health group.*

4. DISCUSSION

As part of a wider dimension called executive functioning, the systematic and repetitive practice of tasks involving working memory and attention which our CSP programme involved, improved frontal lobe functioning significantly more than expected changes associated with spontaneous recovery rates in abstinent alcohol users in rehabilitation. Although our approach was developed for mobile technology to increase accessibility and frequency of cognitive training following its implementation in outpatient clinical populations, at this stage mobility and other related features were not tested. Thus, the improvements found cannot be attributed to these features, but rather to the benefits of stimulating systematically specific cognitive functions during recovery of alcohol dependence. Moreover, the advantage of this approach over traditional CSP, as reported in a previous study of Gamito and colleagues (2013), may be associated with the hedonic aspects of technology as key factors to increase motivation and engagement in the proposed exercises.

In the current study, we focused on comparing its efficacy on the recovery of specific frontal lobe-based functions with that of general cognitive abilities. Because our CSP exercises follow the general standard for these exercises, which are based mostly on training attention, working memory, logical reasoning and attention, having been conceived initially for patients with acquired brain injuries, we expected that they would have a stronger impact on frontal lobe functioning than on general cognitive abilities. The results of neuropsychological assessment have confirmed this prediction. Moreover, this lack of significant differences in the neuropsychological screening may also be related to a ceiling effect because of our exclusion criteria (i.e., only patients with scores above the MMSE cut-off points were selected) that were considered to ensure that patients have the capacity to give their consent to intervention.

Overall, on the one hand, these data indicate a beneficial role of neuropsychological interventions on ADS patients, suggesting that the paths to improve brain function are not limited to substance abstinence, but can be enhanced with neuropsychological interventions (see Goldstein and colleagues, 2005). On the other hand, our results also suggest that training working memory and attention functions gradually and in a systematic manner with mobile technology may be of clinical interest (Gamito et al, 2011). This may be particularly important to improve frontal system functions (Gamito et al, 2013), which is crucial to promote the overall adjustment in these patients.

Acknowledgements: This study was carried out in collaboration with the alcohol rehabilitation unit of the Casa de Saúde do Telhal. We would like to acknowledge the collaboration of the student interns in running the study.

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Virtual reality exposure for trauma and stress-related disorders for city violence crime victims

G Cárdenas-López, A de la Rosa, R Durón, X Durán

School of Psychology,
National Autonomous University of Mexico, Mexico City, MEXICO

cardenas.georgina@gmail.com

ABSTRACT

The criminal violence is attached with mental health problems as depression and substance use and abuse. However one of most important psychological problems linked with the victims of violence is Posttraumatic Stress Disorder (PSTD) and Acute Stress Disorder (ASD). In Mexico, according to the ICESI in 2012, 11% (6,800/for each 100 thousands of habitants) of the population over 18 years experienced a crime. One in four of the people victim of violence develops PSTD symptoms. Due to this socially relevant problem and based on the efficacy of Virtual Reality (VR) treatments, it is important to design treatments involving the use of VR because it can help overcome some of the limitations of traditional therapy using exposure. The present study shows preliminary results of efficacy or virtual reality treatment for PTSD and ASD for crime violence. The clinical sample was conformed for 9 participants from city of Mexico, 6 participants with PTSD diagnoses and 3 participants with ASD diagnoses, aged between 18 and 65. All participants gave informed consent to participate. Treatment was delivered in 90 min individual sessions conducted once a week. Three virtual scenarios for PTSD exposure treatment were used. Improvement was seen in measures of stress, anxiety and depression in both treatment groups, which confirms the clinical efficacious for this technique to treat stress-related disorders.

1. INTRODUCTION

In Mexico crime rates are extremely high: 21.3% of the population over 18 years has suffered from a crime and 86.3% of the population feels unsafe. In recent years, Mexico experienced a dramatic increase in violence. The number of homicides, assault, kidnapping, threats, disappearances, extortions, attacks on civilians, journalists, public officials, human rights advocates, and deaths of bystanders increased substantially. The "National Survey of Urban Public Safety" (ENSU, for its acronym in Spanish, 2013) reported that in the month of September this year (2013) 68% of the population over age 18, considered that living in their own town is highly unsafe, because in the last three months they have witnessed and / or heard of alcohol consumption on the streets (70%), victims of theft or robbery (66.2%) and urban vandalism (56.1%), on the other hand there is a wide variety of factors that children, youth and adults are exposed to, which are highly dangerous, and need to be taken into account in order to create preventive or intervention strategies.

Accordingly, Posttraumatic Stress Disorder (PTSD) and Acute Stress Disorder (ASD) rates caused by criminal violence such as assault, kidnapping or express kidnapping are quite high and continue to increase. The violent situation that exists in the country has generated among survivors fear and insecurity, thus increasing the chances of developing acute stress disorder or posttraumatic stress disorder. This has increased the need for intervention programs for this population. Problems and the consequences related, leading the population to a hopeless sense of fear and insecurity and their repercussions are associated with the PTSD and ASD. Traditional exposure therapies are often difficult to conduct and financially unavailable to most Mexicans; so this new exposure technique using virtual reality environments (VRE) seems a potential tool, which permits both patients and therapists more control and better results. Based on the effectiveness of participants' preference and acceptance for this innovative intervention in a previous controlled study using virtual reality for the treatment of victims, we conduct a study offering treatment at the School of Psychology in Mexico City (Cárdenas, de la Rosa, Flores and Durán, 2013; De la Rosa and Cárdenas, 2012).

The prevalence of PTSD and ASD requires attention because those who suffer from these disorders have elevated degrees of anxiety, fear and avoidance, thereby interfering in personal development and everyday life.

Nowadays there are effective cognitive-behavior therapy (CBT) treatments for PTSD and ASD (Paunovic and Öst, 2001; Tarrier, Liversidge and Gregg, 2006). These treatments employ exposure techniques that help patients to overcome the presence of feared objects or situations related to the traumatic event. Prolonged exposure (PE) is the preferred exposure technique for treating PTSD (Foa, Keane and Friedman, 2000). However this technique is poorly used in clinic treatments (Becker, Zayfert and Anderson, 2004; Van Minnen, Hendriks and Olff, 2010). The low use of these treatments is due to cognitive avoidance of patients to recall traumatic memories and the difficulty for some patients to engage in imaginal exposure.

Virtual reality exposure technique (VRET) can help to overcome some restrictions of traditional exposure therapy (in-vivo or imagined) (Botella, Baños, et al, 2006). VRET can simulate the traumatic situation with a high sense of reality; therefore this can help patients regardless of their ability for imaginal engagement. Another benefit is that therapists can control the characteristics of the situation presented to the patient. These aspects could reduce cognitive avoidance in order to increase the emotional engagement during exposure (Botella, Quero, Serrano, Baños and García-Palacios, 2009).

There are several studies supporting the effectiveness of VR for the treatment of PTSD in different populations (Difede and Hoffman, 2002; McLay, Wood, Weebb-Murphy, Spira, Wiederhold, Pyne et al, 2011; Rizzo, Pair, McNermey, Eastlund, Manson, Gratch et al, 2004; Rothbaum, Hodges, Ready et al, 2001) with survivors of the war, active soldiers and victims of terrorism attacks. In Mexico the development of such systems is non-existent, and its empirical validation is emerging, which gives evidence of the relevance of the study in our socio-cultural context.

Based on this socially relevant problem and centered on the efficacy of previous studies for war violence, our research team initiated a project supported by the National Science and Technology Council, and the municipal government of Ciudad Juarez in Mexico, which purpose was to evaluate the efficacy of a treatment program for PTSD through virtual reality exposure in criminal violence victims and eyewitnesses in Ciudad Juarez. The study reveals a treatment success rate of 80% clinical levels of PTSD and depression were significantly reduced and their level of anxiety was measurably reduced from their pretreatment assessment to post treatment assessment (Cárdenas et al, 2013).

Data obtained from pilot clinical trial in Ciudad Juarez (Cárdenas and de la Rosa, 2012) and a case study in assault with violence in Mexico city (Cárdenas and de la Rosa, 2011a), showed the application of the VR prolonged exposure (PE) technique was effective in reducing symptoms of re-experiencing, avoidance and hyper arousal, which confirms the clinical preference for this technique to treat PTSD. The participant informed feeling comfortable with technology as well as experiencing an improvement in functioning in many areas of his life as a result of treatment. It's relevant to point out previous studies focused to criminal violence in the north part of the country, however it is necessary to inquire about studies supporting the efficacy and clinical relevance of the use of virtual reality to treat PTSD in other types of violent crime in big cities, such as Mexico City, where delinquent acts are increasing and the prevalence of robbery with violence, kidnapping and express kidnapping against civilians is a dramatic reality.

2. METHOD

2.1 Objective

Determinate the efficacy of virtual reality exposure in PTSD and ASD treatment programs for city violence crime victims.

2.2 Participants

The open clinical sample was conformed for participants aged between 18 and 65 years victims and witnesses of assault, kidnapping and criminal violence, who ask to voluntary join the study for psychological services to overcome the PSTD or ASD. The following were inclusion criteria for study participation: a) participants hat to meet criteria for DSM-IV for PTSD with a CAPS score at least 40 (with symptoms rated over the past week) or criteria for ASD with score at least 20 (with symptoms rated over the past week) by: violent assault, "express", kidnapping and/ or kidnapping, b) be between 18 and 65 years of age, and c) voluntary participation in study. The exclusion criteria were a) currently receiving other psychological and/ or pharmacological treatment for PTSD, b) history of or current clinical evidence of severe physical illness or psychoses, c) presence of prominent suicidal ideation, d) not taking psychotropic medication, and e) alcohol and drug abuse.

Nine participants completed treatment, 2 female with a mean age of 36.5 years (*SD*=14.4) and 7 males with a mean age of 34.7 (*SD* =16.39). Suitable participants gave their written consents and were assigned in two types of treatment depending on their initial assessment: prolonged virtual reality exposure for PTSD (n= 6) and prolonged virtual reality treatment for acute stress disorder (n=3). Treatment was delivered between 6 and 10, 90- minute individual sessions conducted once a week. Therapist will use three scenarios for virtual exposure: streets of Mexico City scenario, which includes a pedestrian bridge, an assault/robbery scene and a kidnapping room, in order to expose the patient to the memories of the trauma (Cárdenas and de la Rosa, 2012) that allowed us to recreate situations involving the traumatic event.

2.3 Measures

The following measures were employed:

- *Clinician Administered PTSD Scale, (*CAPS-1; Blake, Weathers and Nagy, 1990). The CAPS-1 is a structured interview developed to test the presence of the 17 DSM-IV-TR criteria for PTSD (re-experimentation, avoiding and hyperactivation). Each symptom is scored on two dimensions: frequency and intensity. Both scales are to be rated on a 5-point scale, ranging from 0 (never and not at all) to 4 (every day and extremely). We used a Mexican version (Palacios, 2002), which inter rater reliability for all three subscales is good (r = 0.851). The cutoff point established for the diagnosis of PTSD is 40 on the global scale.
- *Posttraumatic Stress Symptom Scale, Self Report* (PSS-SR) is a 17 item self-report questionnaire that measures the frequency of PTSD symptoms (Foa, Riggs, Dancu and Rothbaum, 1993). Each item corresponds to one of the DSM-IV-TR criteria for PTSD, and has three subscales: Reexperiencing, avoidance and arousal symptoms. The Mexican version (Almanza, Páez, Hernández, Barajas and Nicolini, 1996) has a Cronbach's alpha of 0.85. The cutoff proposed by the authors is 18 points.
- *State-Trait Anxiety Inventory* (STAI; Spielberger and Diaz, 1975). It consists of two self-rating scales, each scale composed with20 items, which measure two dimensions of anxiety: trait and state. The Mexican version has a Cronbach's alpha of 0.86 for trait scale and 0.54 for state scale.
- *Beck Depression Inventory* (BDI, Beck, 1961) is a 21 item self report that measures affective-cognitive and vegetative-somatic symptoms. The inventory is to be rated of 0-3-point scale, ranging from 0 (no depressive symptoms), 2 (moderate symptom) and 3 (serious symptom). The cutoff point for diagnosis is 14. The Mexican version (Jurado et al, 1998) has a Cronbach's alpha of 0.94.
- *Treatment satisfaction questionnaire* (Borkovec and Nau, 1972; adapted by Botella et al*,* 2009) is a 4 items questionnaire that informs the level of treatment satisfaction, ranging from 1 (none) to 10 (pretty).

The development of the PTSD and ASD virtual reality system models (Cárdenas and de la Rosa, 2011b) was based on the most frequent unsafe locations reported by residents of Mexico City. The system was divided into three interactive environments: the streets of City of Mexico (Fig. 1), an assault/robbery scene in a pedestrian bridge (Fig. 2), a kidnapping vehicle (taxi / wagon) (Fig. 3), and a kidnapping room (Fig. 4). These VREs were considered the social and cultural context appropriate for the target users of the system.

2.4 Design

The experimental design was an open clinical trial with replications, within subject repeated measures (pretreatment and post treatment) (Kazdin, 2007).

2.5 Sample

A non-probability sample was drawn, intentional, subject-type (Kerlinger, 1988).

2.6 Procedure

Participants were administered the measures or interviews at pretreatment and posttreatment, by a licensed clinical psychologist. In the initial interview, participants were informed about the study and treatment. Participants were screened to determine eligibility and provided informed consent for participation. Participants who met initial screening criteria were further evaluated by the CAPS (Blake et al, 1990), Posttraumatic Stress Symptom Scale (Foa et al, 1993), and Self Reports: State-Trait Anxiety Inventory (Spielberger et al, 1975) and Beck Depression Inventory (Beck, 1961). After that were assigned to one of the two treatment conditions: (a) prolonged virtual reality exposure for PTSD and (b) prolonged virtual reality treatment for acute stress disorder. The procedure was carried out in the psychological assistance center at the Psychology school of the National Autonomous University of Mexico.

The treatment program was delivered between 6 and 10; 90- minute individual sessions conducted once a week by three clinical psychologists, one-woman and two men, under the supervision of a more experienced psychotherapist. Therapists were trained in both treatment protocols and the use of virtual reality systems. Treatment success was based on the ability to show a clinically meaningful improvement (30 percent or greater reduction in PTSD symptoms on the Clinician Administered PTSD Scale (CAPS) over the course of 12 weeks.

Figure 1. *City view.*

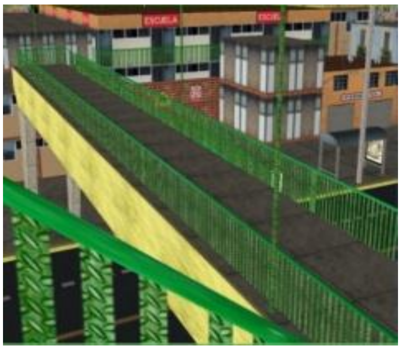


Figure 2. *Bridge view.*

Figure 3. *Taxi view.*

Figure 4. *Kidnapping room view*

2.7 Treatment – PTSD Treatment

Treatment integrity was controlled by PTSD treatment manual adapted for Mexican population (Rothbaum, Difede and Rizzo, 2008). The first therapy session included a presentation of the treatment rationale, education about the disorder, common reactions to trauma, information gathering and breathing relaxation training. Session 2 and 3 focused on traumatic memories, within which the utility of exposure therapy was explained as a medium to confront feared memories and for the processing of the memory. The subsequent sessions (4-10) consisted of 30-45 min. virtual reality exposure: patients are asked to talk about the traumatic event in first person and in present tense, recollecting as many sensory details as vividly as possible. During the exposure, the patient is asked, every 5 min intervals, to report subjective units of distress (SUDS) rating over a scale ranging from 0 to 10. Each exposure session is audiotaped and patients are instructed to listen to the tape at home once a week. From the 4th session onwards in vivo exposure to fearful stimuli associated with the trauma is presented, such like visiting trauma-related places. The final session incorporates relapse prevention techniques and at the conclusion, all participants are requested to complete the questionnaires administered during the initial assessment sessions.

2.8 Treatment – ASD Treatment

Treatment integrity was controlled by ASD treatment manual adapted for Mexican population (Bryant, 2007). The treatment consists in a cognitive-behavioral intervention of 6 weekly sessions of 90 minutes. The first session is focused on explaining the treatment rationale and techniques used, psychoeducation about symptoms and common reactions to trauma, and also training in breathing exercises. The second session focuses on the explanation of the ABC cognitive model for the management of negative automatic thoughts related to trauma, and also to explain the exposure therapy using VR; once the technique is explained the first immersion follows. The third session is focused on explaining In Vivo exposure therapy and the hierarchy of stressful situations is performed, followed by cognitive therapy and exposure through virtual reality. Sessions 4 and 5 continue with prolonged exposure and cognitive therapy, also progress In Vivo Exposure through hierarchies is reviewed. In the sixth and final session the last revision of In Vivo exposure and cognitive therapy is performed, in addition relapse prevention and the post-treatment sessions are scheduled. During exposure therapy, SUDS are used to monitor, from 1 to 10, the levels of anxiety perceived by the patient.

3. RESULTS

3.1 Primary outcome measure

The goal of the study was to identify which treatment resulted in a greater percentage of individuals with a clinically meaningful reduction in PTSD and ASD. This was determined by examining differences in CAPS scores at initial assessment and then at the post-treatment assessment in PTSD prolonged virtual reality exposure and ASD prolonged virtual reality exposure. Scores on the CAPS can range from 0 to 136, with scores above 40 considered clinically significant for PTSD (Weathers, Keane and Davidson, 2001). An improvement of 30 percent or greater on the CAPS is considered a clinically significant change.

3.2 Virtual reality treatment effect: PTSD and ASD

Descriptive statistics for the two scales (CAPS and PTSD symptom scale) are presented in Table 1, which indicates there has been improvement in symptoms for both conditions. All 9 participants who participated in study were assessed with the CAPS at the postassessment, and all of them showed a 30 percent or greater improvement in the CAPS. Two-way analysis of variance showed a significant effect of time (pre- vs. post-treatment, $p<0.001$), but not group ($p>0.05$). There was a significant time-by-group interaction ($p<0.05$). Repeated measures analyses showed that treatment was successful in reducing PTSD and ASD symptoms from pre-treatment to post-treatment.

Data showed statistical difference from pre-test to post-test in PTSD virtual reality exposure treatment group in the *Clinician Administered PTSD Scale* (CAPS) ($T_{(2, 19)} = 4.31$, $p = 0.001$).

Table 1. *Mean, standard deviations results obtained for PTSD symptoms.*

Measure	Virtual reality exposure treatment (VRET) (n = 6)	
	Pre-treatment M (SD)	Post-treatment M (SD)
CAPS	79.2 (29.9)	7.9 (6.1)
CAPS Re-experiencing	24.2 (9.3)	2.8 (3.1)
CAPS Avoidance	32. 2 (13.2)	2.3 (1.8)
CAPS Hyperarousal	24.1 (9.2)	2.8 (2.3)
PTSD Symptom Scale	32.5 (9.3)	5.7 (3.4)

Regarding the *PTSD Symptom Scale,* as shown in Figure 5 and 6, scores by participants showed significant differences between pre-treatment and posttreatment and also in both treatment groups. The same occurred for the *state anxiety* (T =2.3, p = 0.01) (Figure 7) and the *depression* measure (T = 1.5, p = 0.01) (Figure 8).

Finally, in the results from the *Treatment satisfaction questionnaire*, all participants obtained significant changes in these variables after treatment, which demonstrates improvement for both treatment conditions.

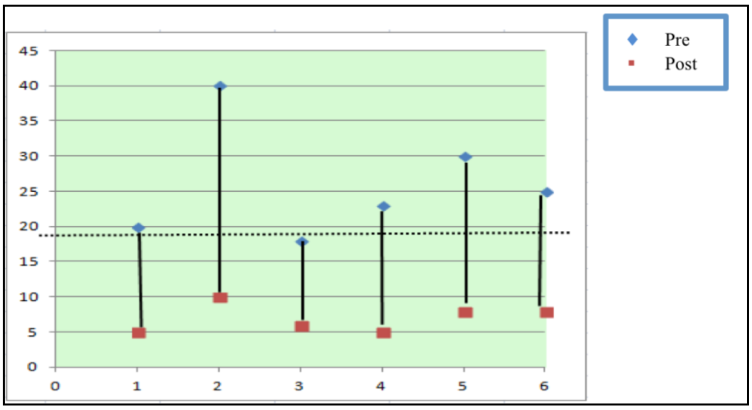


Figure 5. *Data obtained for PTSD symptoms in the VRET (n=6).*

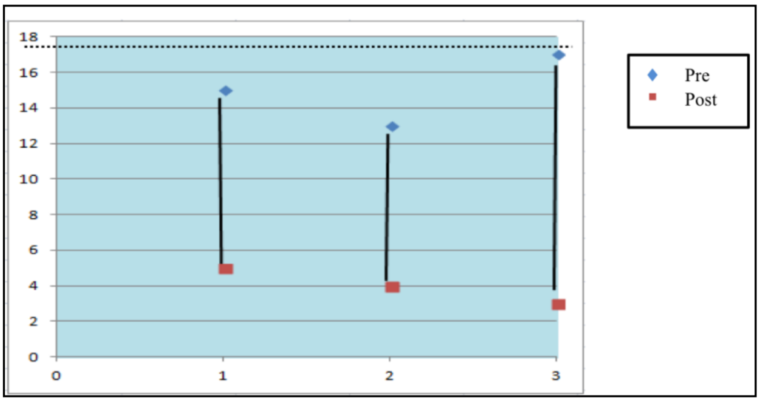
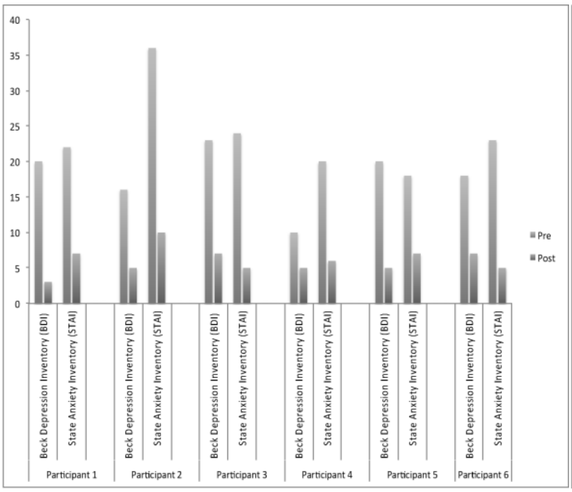


Figure 6. *Data obtained for ASD symptoms in the VRET (n=3).*



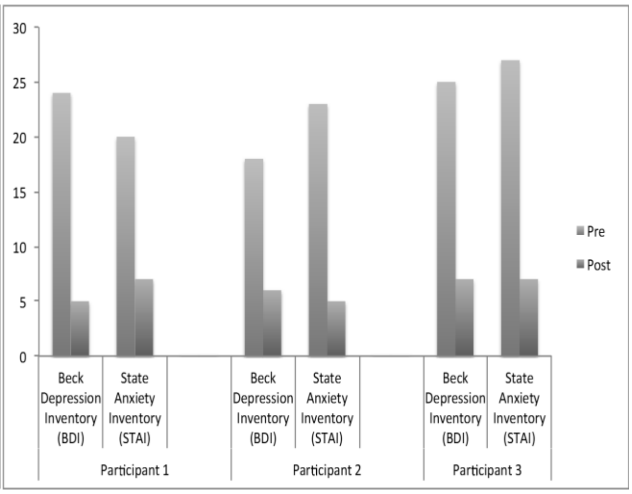


Figure 7. *State anxiety and depression measures in the PTSD.* **Figure 8**. *State anxiety and depression measures in the ASD.*

4. CONCLUSIONS

The primary goal of this study was to examine the efficacy of virtual reality exposure in two treatments: PTSD and ASD. Results indicate that 100 percent of participants who received VRT showed a clinically significant (>30 percent) improvement in their PTSD symptoms after 12 weeks of treatment.

The response rates seen here are similar to those reported in previous, single-group design studies that have investigated VR-based therapies (Gahm, Reger, Ingram, Reger and Rizzo, 2013; Opriş, Pintea, García-Palacios, Botella, Szamosközi and David, 2012) as well as for other forms of exposure therapy for PTSD.

From data obtained from a case study (Cárdenas and de la Rosa, 2011a) and pilot open clinical trial, application of the VR exposure technique was effective in reducing symptoms of re-experiencing, avoidance and hyper arousal, which confirms the clinical preference for this technique to treat PTSD and ASD. The participant informed the therapists of feeling comfortable with the technology, as well as experiencing an improvement in functioning in many areas of his life as a result of treatment.

Improvement was seen in the intragroup measures of PTSD, anxiety and depression for both groups receiving treatment. Data confirm the results of background studies regarding the effectiveness of treatment using virtual reality, supporting the generalizability of empirically validated treatments that have shown effectiveness and efficiency in the treatment of victims of such violence in the Mexican population.

Participants showed lower scores on the subscale of avoidance symptoms, implying a greater ability from the participant's to generalize what they learned during the virtual reality therapy session to everyday life situations. This confirms the findings of Botella, Quero, Serrano, Baños and García-Palacios (2009) and Rizzo, Gerardi, Rothbaum, Ressler and Heekin (2008) on the contribution of virtual reality to reduce cognitive avoidance and therefore enhance the generalization of change in the exposure to real stimuli. Therefore, the results suggest exploring in future studies the mechanisms and moderators of clinical change that explain the effectiveness of exposure through virtual reality technologies and its differential impact on reducing post-traumatic symptoms.

Regarding the satisfaction of the participants once concluded the treatment; there were no difference in preference between the VRET condition and the IET condition. Participants consider both treatments useful and would recommend it to a friend or family member to address de issue of PTSD. However, there were significant differences in the in the degree of aversion evaluated by the participants, which is consistent with the stated by García-Palacios, Botella, Hoffman and Fabregat (2007) and Rizzo *et al*. (2008) by affirming that is easier for participants to take the first step to face their fear when they can do it through virtual environments.

In particular, the creation of VR environments for these manifestations of violence offers many advantages ranging from cost savings, design of safe treatment environments, stimulus control, and feedback for both patient and clinician. Additionally, their validation represents a great impact in our country as well as support for the dissemination of empirically validated interventions for the treatment of pathological grief, PTSD and adaptive disorders highly related to these new threats to psychological wellbeing.

Although these initial results are promising, the study conducted was limited. Unfortunately, the sample size was too small, not blinded assessment, did not have a control group that allowed for a wide variety of possible treatments, and did not include long-term follow up.

Finally, it is noted that the study population has individual characteristics that made difficult to recruit the sample and therefore it was not possible to work with larger groups of people. Most participants had economic problems that prevented them from going to therapy, some were involved in legal proceedings that forced them to continually confront the memory of the traumatic event and led to treatment discontinuation.

Acknowledgements: Research and Technological Innovation Projects Support Program (PAPIIT, for its acronym in Spanish) founded this project.

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Detection and computational analysis of psychological signals using a virtual human interviewing agent

A A Rizzo, S Scherer, D DeVault, J Gratch, R Artstein, A Hartholt, G Lucas, S Marsella, F Morbini, A Nazarian, G Stratou, D Traum, R Wood, J Boberg, L-P Morency

Institute for Creative Technologies, University of Southern California,
12015 East Waterfront Dr., Playa Vista, Los Angeles, California, USA

rizzo@ict.usc.edu, scherer@ict.usc.edu, devault@ict.usc.edu, gratch@ict.usc.edu, artstein@ict.usc.edu, lucas@ict.usc.edu, marsella@ict.usc.edu, morbini@ict.usc.edu, angelana@usc.edu, stratou@ict.usc.edu, traum@ict.usc.edu, rwood@ict.usc.edu,boberg@ict.usc.edu, morency@ict.usc.edu

http://ict.usc.edu/

ABSTRACT

It has long been recognized that facial expressions, body posture/gestures and vocal parameters play an important role in human communication and the implicit signalling of emotion. Recent advances in low cost computer vision and behavioral sensing technologies can now be applied to the process of making meaningful inferences as to user state when a person interacts with a computational device. Effective use of this additive information could serve to promote human interaction with virtual human (VH) agents that may enhance diagnostic assessment. The same technology could also be leveraged to improve engagement in teletherapy approaches between remote patients and care providers. This paper will focus on our current research in these areas within the DARPA-funded "Detection and Computational Analysis of Psychological Signals" project, with specific attention to the *SimSensei* application use case. *SimSensei* is a virtual human interaction platform that is able to sense and interpret real-time audiovisual behavioral signals from users interacting with the system. It is specifically designed for health care support and leverages years of virtual human research and development at USC-ICT. The platform enables an engaging face-to-face interaction where the virtual human automatically reacts to the state and inferred intent of the user through analysis of behavioral signals gleaned from facial expressions, body gestures and vocal parameters. Akin to how non-verbal behavioral signals have an impact on human to human interaction and communication, SimSensei aims to capture and infer from user non-verbal communication to improve engagement between a VH and a user. The system can also quantify and interpret sensed behavioral signals longitudinally that can be used to inform diagnostic assessment within a clinical context.

1. INTRODUCTION

It has long been recognized that facial expression and body gestures play an important role in human communicative signalling (Ekman and Rosenberg, 1997; Russell and Fernandez-Dols, 1997). As well, vocal characteristics (e.g., prosody, pitch variation, etc.) have also been reported to provide additive information regarding the "state" of the speaker beyond the actual language content of the speech (Pentland et al, 2009). While some researchers postulate that the universal expression and decoding of face/body gestures and vocal patterns are indicative of genetic "hardwired" mammalian neural circuitry as Darwin proposed over a hundred years ago (Darwin, 2002), others have placed less emphasis on investigating underlying mechanisms and instead have focused on the empirical analysis of such implicit communication signals and what can be meaningfully derived from them. In the latter category, Pentland's MIT research group has characterized these elements of behavioral expression as "Honest Signals" (Pentland, 2008). Based on his research with groups of people interacting, he suggests: *"…this second channel of communication, revolving not around words but around social relations, profoundly influences major decisions in our lives—even though we are largely unaware of it."* Pentland posits that the physical properties of this signalling behavior are constantly activated, not simply as a back channel or complement to our conscious language, but rather as a separate communication network. It is conjectured that these signalling behaviors, perhaps evolved from ancient primate non-verbal communication mechanisms, provide a useful window into our intentions, goals, values and emotional state.

Based on this perspective, an intriguing case can be made for the development of a computer-based sensing system that can capture and quantify such behavior, and from that activity data make inferences as to a user's cognitive and emotional state. Inferences from these sensed signals could be used to supplement information that is garnered exclusively from the literal content of speech for a variety of purposes. This is one of the major premises of the interdisciplinary research area of affective computing that focuses on the study and development of systems and devices that can recognize, interpret, process, and simulate human affective states. This vision had been discussed early on in the human computer interaction (HCI) literature in the context of perceptual user interfaces (PUI) (Turk and Robertson, 2000). PUIs are user interfaces that maximize the bandwidth of communication between a user and a computational device with such sensing technologies, and aims to enable a user experience with computers that is more similar to the way that people interact with each other face to face. The expectation that PUIs could provide incremental value over traditional HCI methods rests on the premise that more sophisticated forms of bi-directional interaction between a computational device and a human user will produce a more naturalistic engagement between these two complex systems. This is not a new idea, and one can find references to these concepts going back to Picard (1995), and the concept was well summarized on the IBM Almaden legacy website in 2000: *"Just as a person normally expects a certain kind of engagement when interacting with another person, so should a person be able to expect similar engagement when interacting with a computational device. Such engagement requires the computer to carefully observe the user, anticipating user actions, needs, and desires. Such engagement enables users to begin to build personal relationships with computers."* (Blue eyes: Suitor [WWW Document]. URL http://www.almaden.ibm.com/cs/blueeyes/suitor.html, visited 2001, February 2).

Recent progress in low cost sensing technologies and computer vision methods have now driven this concept closer to reality and the use cases for such applications can now be extended beyond enhancing basic HCI. Indeed, recent widespread availability of low cost sensors (webcams, Microsoft Kinect, microphones) combined with software advances for facial feature tracking, articulated body tracking, and voice analytics (Baltrusaitis et al, 2012; Morency et al, 2008; Whitehill et al, 2009) has opened the door to new applications for automatic nonverbal behavior analysis. For example, computer vision systems and voice analytic algorithms that are available during a standard clinical session could assist clinicians and health care providers in their daily activities by providing additive predictive information as to patient "state" to supplement the clinician's awareness of subtle behaviors that could enhance clinical decision making. Such automatic behavior descriptors could be unobtrusively captured across the course of a clinical session and this quantitative information on behavior dynamics and intensities could be available to the clinician in real time (via earphones or a personal monitor) as well as providing deeper quantitative analysis for post-session review and longitudinal analysis across multiple sessions. Another promising area is in the enhancement of engagement in Teleheath/Teletherapy approaches between remote patients and care providers. Such new perceptual software could assist clinicians during teletherapy sessions where the capture and delivery technology may provide less than optimal or impoverished audiovisual communication cues relative to those provided in direct face-to-face interactions. In this teletherapy case, sensed behavioral cues could be analyzed and delivered in the form of a real time decision support visualizations to aid the clinicians' awareness of patient state (See Figure 1a). Moreover, short of direct delivery of this information to a clinician, the sensing and quantification of nonverbal behavioral cues can also provide input to an interactive virtual human coach that would be able to offer advice based on perceived indicators of user distress or anxiety during a short interview. This is the primary effort that we will detail in this paper with our presentation of the "SimSensei" interviewing agent (See Figure 1b).

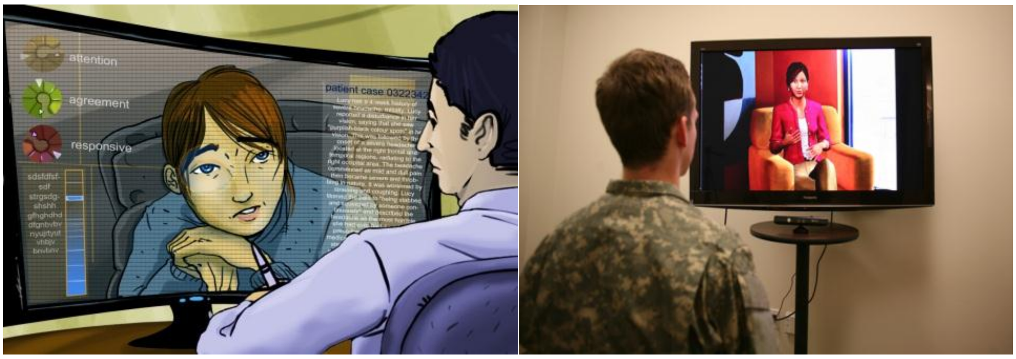

Figure 1. *(a) Telecoach interface concept (on left) and (**b**) SimSensei virtual health agent (on right).*

2. SIMSENSEI AND MULTISENSE

SimSensei is one application component of our recent research and development within the DARPA-funded "Detection and Computational Analysis of Psychological Signals (DCAPS)" project. This DCAPS application has aimed to explore the feasibility of creating "empathic" virtual human health agents for mental health screening. The private kiosk-based SimSensei system was envisioned to be capable of conducting interviews with patients who may be initially hesitant or resistant to seeking traditional mental health care with a live provider (See Figure 1b). The system seeks to combine the advantages of traditional web-based self-administered screening (Weisband and Kiesler, 1996), which allows for anonymity, with anthropomorphic interfaces which may foster some of the beneficial social effects of face-to-face interactions (Kang and Gratch, 2012). SimSensei evolves an earlier web-based screening tool, SimCoach (Rizzo et al, 2011), and can engage users in a structured interview using natural language and nonverbal sensing with the aim of identifying behaviors associated with anxiety, depression or PTSD.

The SimSensei capability to accomplish this was supported by the "MultiSense" perception system (Morency et al, http://multicomp.ict.usc.edu/?p=1799; Devault et al, 2014). This is a multimodal system that allows for synchronized capture of different modalities such as audio and video, and provides a flexible platform for real time tracking and multimodal fusion. This is a very important aspect of the system in that it enables fusion of modality "markers" to support the development of more complex multimodal indicators of user state. MultiSense dynamically captures and quantifies behavioral signals such as 3D head position and orientation, type, intensity and frequency of facial expressions of emotion (e.g., fear, anger, disgust and joy), fidgeting, slumped body posture, along with a variety of speech parameters (speaking fraction, speech dynamics, latency to respond, etc.). These informative behavioral signals serve two purposes. First, they produce the capability of analyzing the occurrence and quantity of behaviors to inform assessment. Second, they are broadcast to the other components of SimSensei Kiosk to inform the virtual human interviewer of the state and actions of the participant and assist with turn taking, listening feedback, and building rapport by providing appropriate non-verbal feedback. MultiSense serves to fuse information from web cameras, the Microsoft Kinect and audio capture and processing hardware to identify the presence of any nonverbal indicators of psychological distress and to provide moment-to-moment inferences to the SimSensei virtual agent "who" may act upon that information to provide supportive feedback, deliver acknowledging gestures/facial expressions and drive follow on questions. In depth technical details of the Multisense software as well as the SimSensei dialog management, natural language system, and agent face and body gesture generation methods are beyond the scope of this article and can be found elsewhere (DeVault et al, 2014; Scherer et al, 2013).

3. NON-VERBAL BEHAVIOR AND CLINICAL CONDITIONS

To begin to develop a corpus of automatic nonverbal behavior descriptors that Multisense could track for the SimSensei application, we searched the large body of research that has examined the relationship between nonverbal behavior and clinical conditions. Most of this research resided in the clinical and social psychology literature and until very recently the vast majority relied on manual annotation of gestures and facial expressions. Despite at least forty years of intensive research, there is still surprisingly little progress on identifying clear relationships between patient disorders and expressed behavior. In part, this is due to the difficulty in manually annotating data, inconsistencies in how both clinical states and expressed behaviors are defined across studies, and the wide range of social contexts in which behavior is elicited and observed. However, in spite of these complexities, there is general consensus on the relationship between some clinical conditions (especially depression and social anxiety) and associated nonverbal cues. These general findings informed our initial search for automatic nonverbal behavior descriptors.

For example, gaze and mutual attention are critical behaviors for regulating conversations, so it is not surprising that a number of clinical conditions are associated with atypical patterns of gaze. Depressed patients have a tendency to maintain significantly less mutual gaze (Waxer, 1974), show nonspecific gaze, such as staring off into space (Schelde, 1998) and avert their gaze, often together with a downward angling of the head (Perez and Riggio, 2003). The pattern for depression and PTSD is similar, with patients often avoiding direct eye contact with the clinician. Emotional expressivity, such as the frequency or duration of smiles, is also diagnostic of clinical state. For example, depressed patients frequently display flattened or negative affect including less emotional expressivity (Perez and Riggio, 2003; Bylsam et al, 2008), fewer mouth movements (Fairbanks et al, 1982; Schelde, 1998), more frowns (Fairbanks et al, 1982; Perez and Riggio, 2003), and fewer gestures (Hall et al, 1995; Perez and Riggio, 2003). Some findings suggest it is not the total quantity of expressions that is important, but their dynamics. For example, depressed patients may frequently smile, but these are perceived as less genuine and often shorter in duration (Kirsch and S. Brunnhuber, 2007) than what is found in non-clinical populations. Social anxiety and PTSD while sharing some of the features of depression, also have a tendency for heightened emotional sensitivity and more energetic responses including hypersensitivity to stimuli: e.g., more startle responses, and greater tendency to display anger (Kirsch and S. Brunnhuber, 2007), or shame (Menke, 2011). Fidgeting is often reported with greater frequency in clinical populations. This includes gestures such as tapping or rhythmically shaking hands or feet and has been reported in both anxiety and depression (Fairbanks et al, 1982). Depressed patients also often engage in "self-adaptors" (Ekman and Friesen, 1969), such as rhythmically touching, hugging or stroking parts of the body or self-grooming, such as repeatedly stroking the hair (Fairbanks et al, 1982). Examples of observed differences in verbal behavior in depressed individuals include increased speaker-switch durations and diminished variability in vocal fundamental frequency (Cohn et al, 2009), decreased speech output, slow speech, delays in delivery, and long silent pauses (Hall et al, 1995). Differences in certain lexical frequencies have been reported including use of first person pronouns and negatively-valenced words (Rude et al, 2004).

One recent brewing controversy within the clinical literature is whether certain specific categories of mental illness (e.g., depression, PTSD, anxiety, and schizophrenia) reflect discrete and clearly separable conditions or rather, continuous differences along some more general underlying dimensions (Russell and Barrett, 1999). This parallels controversies in emotion research as to whether emotions reflect discrete and neurologically distinct systems in the brain, or if they are simply labels we apply to differences along broad dimensions such as valence and arousal. Indeed, when it comes to emotion recognition, dimensional approaches may lead to better recognition rates than automatic recognition techniques based on discrete labels. The broad dimension receiving the most support in clinical studies is the concept of general psychological distress. For example, (Elhai et al, 2011) examined a large number of clinical diagnostic interviews and found that diagnoses of major depression and PTSD were better characterized by considering only a single dimension of general distress. Several other researchers have statistically re-examined the standard scales and interview protocols used to diagnose depression, anxiety and PTSD and found they highly correlate and are better seen as measuring general distress (Bieling et al, 1998; Marshall et al, 2010; Arbisi, et al, 2012). For this reason, we have investigated if general distress may be a more appropriate concept for recognizing clinical illness in addition to the more conventional discrete categories.

Thus, the key challenge when building such nonverbal perception technology for clinical applications is to develop and validate robust descriptors of human behaviors that are correlated with psychological distress. These descriptors should be designed to probabilistically inform diagnostic assessment or quantify treatment outcomes. However, no descriptor is completely diagnostic by itself, but rather may reveal "tendencies" in user's non-verbal behaviors that are informational to enhance clinical hypothesis testing and/or decision making. As a first step, we relied on three main sources of information to identify such behaviors: a literature review on nonverbal behaviors indicative of psychological conditions as reported by clinical observations and by existing work on automatic analysis (Fairbanks et al, 1982; Hall et al, 1995; Kirsch and Brunnhuber, 2007; Perez and Riggio, 2003), a qualitative analysis based on observations from the videos, and consultation with experts (including trained clinicians) who looked at the data and identified the communicative behaviors that they would use to form a diagnosis. As a next step, selected behaviors were quantified on the face-to-face corpus via manual annotation. The selection criteria for which behaviors to prioritize for annotation was based on diagnostic power and implementability. Initially, face-to-face interview data is utilized as a study ground to identify nonverbal behaviors that are correlated with depression, PTSD, and anxiety. Following the analysis of face-to-face human interactions to identify potential emotional indicators, dialogue policies, and commonality of human gestures, the development and analysis of a Wizard-of-Oz (WoZ) prototype system was required. The WoZ interaction allowed human operators to choose the spoken and gestural responses of a virtual human character (similar to digital puppetry) that interacted with a live research participant. The final step involved the development of a fully automatic virtual interviewer (SimSensei) that is able to engage users in 15-25 minute interactions.

4. DYADIC FACE-TO-FACE INTERACTION DATASET

The fundamental novel research challenge in this project is to endow computers with the ability to recognize clinically-relevant information from the nonverbal behavior of patients. Computer vision and audio signal processing techniques have shown growing success in identifying a number of important nonverbal cues but the limitation of state-of-the-art approaches is that they are data hungry: they require large amounts of annotated data. Thus, our initial milestone was to collect a large dataset of clinical interviews with participants known to have a high likelihood of PTSD, social anxiety and depression and to identify and annotate their nonverbal behaviors relevant to finding indicators of these clinical states.

4.1 Participants

One hundred and seventy seven participants were recruited from two distinct populations. 120 participants (86 male) were recruited from the Los Angeles general population through Craigslist, an online job posting service. 57 participants (49 male) were recruited from *U.S. Vets*, a non-profit organization that helps very troubled military veterans re-integrate into civilian life after leaving the service and has programs tailored for veterans with PTSD and depression. Participants were informed that we are interested in their experience with PTSD and depression.

4.2 Procedure

After obtaining informed consent, participants were led to a computer and, in private, completed a series of web-delivered psychometric scales to assess clinically-relevant states and traits. These included the PTSD Checklist-Civilian version (PCL-C) to assess PTSD (Blanchard et al, 1996), Patient Health Questionnaire-Depression 9 (PHQ-9) to assess depression (Kroenke et al, 2001) the State/Trait Anxiety Inventory (STAI) to assess state anxiety (Spielberger et al, 1970), the PANAS to assess current mood (Watson et al, 1988) and the Balanced Inventory of Desirable Responding (BIDR) to assess tendencies to be deceptive in such interview contexts (Paulhus, 1988). The web-based assessment was followed by a 30-minute structured interview that explored if they had been previously diagnosed and are currently experiencing symptoms of PTSD, depression and anxiety and to elicit data relating clinical states with nonverbal behavior. Two possible interviewers conducted the interview which consisted of three phases, as warm-up phase consisting of basic questions designed to establish rapport (e.g., "How is your day going? Where are you from"), an interview phase where participants were asked to elaborate on some of their responses to the scales (e.g., "On the survey you mention you often experience disturbing thoughts; can you tell me a little more about that?"), followed by a wind-down phase designed to return the participant to a more pleasant state of mind (e.g., "If you could travel to any destination, where would you go?"). During the interview phase, both the participant and the interviewer are fitted with a lapel microphone and are recorded with video cameras and the Kinect system to track their body posture. The video cameras and Kinect are placed between the participants. Following the interview, we assessed the quality of the interaction with measures of rapport and social presence.

4.3 Subject Variable Summary Statistics

Overall, about 32% of the subjects were assessed positive for PTSD, 29% for depression, and 62% for trait anxiety. Participants from U.S. Vets were assessed positive more often for each of the disorders, as was expected, and they were demonstrably different from the Craigslist population in several ways. Demographically, U.S. Vets subjects were older, less educated, more likely to be male, and less likely to be employed. They were also much more likely to have been a member of the armed forces, as expected, since we intentionally chose that population for our experiment. Subjects with assessed disorders were significantly different on several measures: They scored significantly higher in neuroticism and were more anxious before the interview. Consistent with the findings on general distress discussed earlier, we observed significant correlations ($p<0.01$) between the disorders (i.e. PTSD, anxiety, and depression). Diagnosis for depression correlated with PTSD ($\rho = 0.64$, using Pearson's correlation), depression correlated with anxiety ($\rho = 0.40$) and PTSD correlated with anxiety ($\rho = 0.43$). When conserving the scalar severity measure of the three inventories, we found even stronger correlations ($\rho > 0.8$). Based on the prior findings on general distress and the comorbidity observed in this dataset, we concluded that at this stage in the research, automatic recognition techniques should focus on recognizing indicators of general distress rather than attempting to distinguish individual conditions. As a result, we used factor analysis to identify a single indicator of distress that is used in subsequent training and analysis.

4.4 Clinical Cue Results

The dataset was annotated with manual and automatic techniques to identify nonverbal (audio and visual) behaviors that might be associated with generalized distress. All manual annotators were trained until they reached high inter-coder agreement. Manual features include hand self-adaptors (i.e., self-touching) and leg fidgeting. Automatic features included head orientation, gaze angle, smile intensity and duration and several features related to vocal quality.

We found several statistically significant differences in the behavior of participants between those that scored positive for general distress and normal controls. (1) There are significant differences in the automatically estimated gaze behavior of subjects with psychological disorders. In particular, an increased overall downwards angle of the gaze could be automatically identified using two separate automatic measurements, for both the face as well as the eye gaze. (2) We could also identify on average significantly less intense smiles for subjects with psychological disorders as well as significantly shorter average durations of smiles (see Figure 2). (3) Based on the manual analysis, subjects with psychological conditions exhibit on average longer self-touches and fidget on average longer with both their hands (e.g. rubbing, stroking) as well as their legs (e.g. tapping, shaking).

We found several significant differences in the vocal patterns of participants with general distress related to the 'coloring' of the voice when compared with normal controls (for this we only analyzed male participants to control for differences in vocal quality that arise from gender). We examined differences in vocal fundamental frequency, speech intensity, measures of monotonicity (i.e. intensity variations and spectral stationarity), and measures of the voice's breathiness (e.g. normalized amplitude quotient (NAQ)). The most promising findings are that the speech intensity variations of distressed subjects are significantly reduced and their voice quality is significantly breathier based on the observed NAQ parameter. These results replicate findings in the psychological literature and give us confidence that these indicators can be identified automatically in real-time interactions using low-cost sensors.

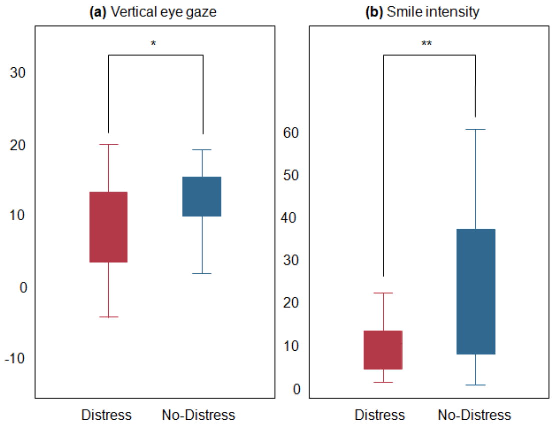

Figure 2. *Example of two automatic behavior descriptors. Boxplots show significantly stronger overall downward angle of the (a) eye gaze (p<0.05) and (b) a significantly lowered average smile intensity (p<0.01) for "distressed" participants.*

Table 1. *Evaluation of Automatic Non-verbal Behavior Analysis. Comparison across clinical conditions (distressed, depression, anxiety, PTSD).*

	Tier	Condition μ (σ)	No-Condition μ (σ)	p	g
Distress	VHead Gaze	0.14 (0.11)	0.19 (0.10)	**0.04**	-0.46
	VEye Gaze	8.93 (7.92)	13.65 (6.30)	**0.01**	-0.64
	Smile Int.	12.31 (10.09)	23.76 (18.30)	**<0.01**	-0.75
	Smile Dur.	2.49 (0.87)	3.43 (1.85)	**0.01**	-0.63
Depression	VHead Gaze	0.15 (0.11)	0.17 (0.09)	0.20	-0.19
	VEye Gaze	9.83 (7.35)	11.56 (6.69)	0.16	-0.25
	Smile Int.	12.81 (11.14)	19.94 (16.85)	**0.04**	-0.45
	Smile Dur.	2.59 (0.87)	3.02 (1.69)	0.15	-0.27
Anxiety	VHead Gaze	0.15 (0.10)	0.19 (0.10)	0.06	-0.36
	VEye Gaze	10.05 (7.87)	12.87 (4.04)	**0.04**	-0.41
	Smile Int.	14.77 (13.33)	23.52 (18.15)	**<0.01**	-0.56
	Smile Dur.	2.66 (1.25)	3.33 (1.87)	**0.03**	-0.44
PTSD	VHead Gaze	0.14 (0.11)	0.18 (0.09)	**0.04**	-0.39
	VEye Gaze	9.37 (8.12)	11.86 (6.11)	0.07	-0.36
	Smile Int.	12.25 (10.78)	20.85 (17.11)	**0.01**	-0.55
	Smile Dur.	2.37 (0.81)	3.17 (1.73)	**0.02**	-0.52

5. WIZARD-OF-OZ AND AUTOMATIC VH AGENT INTERVIEW DATASETS

The next step was to conduct a Wizard-of-Oz (WoZ) study where participants interacted with a female VH character named "Ellie" whose speech and behavior responses were controlled by two "behind the curtain" operators. In this setup, a fixed set of 191 speech utterances and 23 nonverbal behaviors were defined and made available to two Wizards who jointly controlled Ellie's behavior (one controlled speech, the other controlled behavior). This two-wizard arrangement was necessary as the task of controlling both Ellie's verbal and nonverbal behavior proved difficult for a single wizard to coordinate. In addition to asking the relevant interview questions, these options provided the Wizard- controlled Ellie with a finite, circumscribed repertoire of response options to try to act as a good listener. Ellie could also provide backchannel activity, empathy and surprise responses, and continuation prompts. The set of options that was made available to the two Wizards is summarized in Table 2.

Table 2. *Wizard-of-Oz Option Set.*

Option Type	Example
nonverbal behaviors	head nod to indicate agreement
interview questions	*what are you like when you don't get enough sleep?*
neutral backchannels	*uh huh*
positive empathy	*that's great*
negative empathy	*i'm sorry*
surprise responses	*wow!*
continuation prompts	*could you tell me more about that?*
miscellaneous	*i don't know; thank you*

A sample of 140 participant interactions were collected using the WoZ system applying the same methodology, sample sources, and assessment devices used in the previous face-to-face condition. Analysis of these dialogues confirmed the presence of significant differences in the non-verbal behavior of distressed participants when

Proc. 10th Intl Conf. Disability, Virtual Reality & Associated Technologies
Gothenburg, Sweden, 2–4 Sept. 2014
©2014 ICDVRAT; ISBN 978-0-7049-1546-6

compared to non-distressed participants (Scherer, et al, 2013ab; Stratou et al, 2013) and also differences in the verbal behavior of distressed participants when compared to non-distressed participants (DeVault et al, 2013). These significant differences confirmed that the finite set of wizard utterances and non-verbal behavior options was adequate to conduct interviews that could elicit different responses and behaviors from distressed individuals than from non-distressed individuals. WoZ results in the context of comparison with face-to-face and Automatic VH agent are presented in the next section.

6. COMPARATIVE EVALUATION ACROSS INTERVIEWS: FACE-TO-FACE, WOZ, AND AUTOMATIC INTERACTION (AI) WITH A VH AGENT

The next step in the development of the system was integration into a SimSensei Kiosk. More specifically, the perception system's functionality was tuned to automatically track and recognize nonverbal behaviors that are important for psychological condition assessment, as reported from the previous steps, but in the context of an interview with an autonomous VH agent (still Ellie). The key sensed behaviors associated with depression, anxiety, and PTSD were extracted live during the interview, were used to guide Ellie's interactive behavior and the summary statistics were available automatically at the end of the interview. In this stage the focus was on the capture and analysis of such behavioral signals in the real-time system and the validation of the previous analysis of face-to-face data on the new corpus of fully automated interactions. We compared the three interview datasets: face-to-face, Wizard-of-Oz, and "AI interactions" where the VH was controlled by the automated SimSensei Kiosk system (referred to as AI).

6.1 Participants and Procedures

Across all three studies, 351 participants were recruited through Craigslist and from posted flyers. Of the 120 face-to-face participants, 86 were male and 34 were female. These participants had a mean age of 45.56 (SD = 12.26). Of the 140 WoZ participants, 76 were male, 63 were female, and 1 did not report their gender. The mean age of this group of participants was 39.34 (SD = 12.52). Of the 91 AI participants, 55 were male, 35 were female, and 1 did not report their gender. They had a mean age of 43.07 (SD = 12.84).

All participants were given a series of self-report assessment instruments to index their clinical state, as described above. Post-experience, all participants completed a validated measure of rapport (Kang and Gratch, 2012). Additionally, participants in WoZ and AI completed nine questions designed to test our success in meeting specific VH design goals (see Table 3). Examples include questions about disclosure ("I was willing to share information with Ellie"), the mechanics of the interaction ("Ellie was sensitive to my body language") and willingness to recommend the system to others. All were rated on a scale from 1 (strongly disagree) to 5 (strongly agree). Note that in the WoZ condition, participants were told that the agent was autonomous and not puppeted by two people. Finally, participants in WoZ and AI also completed the standard System Usability Scale (Brooke, 1996), a measure of a product's perceived system satisfaction and usability.

6.2 Results

For all items and scales, participants' total scores were calculated for analysis. Table 3 displays mean total scores and associated standard errors for each of the subsequent analyses. With regard to the design goals, most participants agreed or strongly agreed they were achieved, whether they interacted with the Wizard-operated or AI system. For example, most people agreed or strongly agreed that they were willing to share information with Ellie (84.2% WoZ; 87.9% AI), were comfortable sharing (80.5% WoZ; 75.8% AI) and did share intimate information (79.3% WoZ; 68.2% AI). Both systems performed less well with regard to their perceived ability to sense and generate appropriate nonverbal behavior. For example, a minority of participants agreed or strongly agreed that Ellie could sense their nonverbal behavior (40.3% WoZ; 27.5% AI). However, this did not seem to seriously detract from the overall experience and majority agreed or strongly agreed they would recommend the system to a friend (69.8% WoZ; 56.1% AI).

We next examined the relative impressions of the AI system when compared with the Wizard-of-Oz. Although the AI is in no way intended to reach human-level performance, this comparison gives insight in areas that need improvement. First, we conducted t-tests to compare Wizard-of-Oz to AI on each of the individual items representing the system's design criteria. Surprisingly, results yielded only one significant difference. WoZ participants reported feeling that the interviewer was a better listener than the AI participants ($t(166) = 3.94$, $p < .001$, $d = 0.61$). Next, we conducted t-tests comparing WoZ to AI on System Usability scores and on ratings of rapport. WoZ participants rated the system as higher in usability than AI participants ($t(229) = 3.24$, $p = .001$, $d = 0.44$) and also felt more rapport ($t(229) = 3.28$, $p = .001$, $d = 0.44$).

Finally, we examined how the WoZ and AI systems compared with the original face-to-face interviews (see Table 4). We conducted an ANOVA to compare ratings of rapport for the three methods. Results revealed a significant effect of method on rapport ($F(2, 345) = 14.16$, $p < .001$, $d = 0.52$). Interestingly, this effect was driven by the WoZ. WoZ participants felt greater rapport than AI participants ($t(345) = 3.87$, $p < .001$, $d = 0.42$ and compared to face-to-face participants ($t(345) = -4.95$, $p < .001$, $d = 0.53$). Surprisingly, AI and face-to-face participants' ratings of rapport did not differ ($t(345) = -0.77$, $p = .44$, $d = 0.07$.).

Table 3. *Means, Standard Errors, t-values and effect sizes on design questions * = <.05.*

Design Goals	Method		t-value	d
	WoZ	AI		
I was willing to share information with Ellie	4.03 (0.83)	4.07 (0.73)	-0.33	0.05
I felt comfortable sharing information with Ellie	3.92 (0.98)	3.80 (1.07)	0.75	0.12
I shared a lot of personal information with Ellie	3.97 (1.04)	3.73 (1.14)	1.47	0.23
It felt good to talk about things with Ellie	3.69 (1.02)	3.60 (0.95)	0.55	0.08
There were important things I chose to not tell Ellie	2.93 (1.19)	2.66 (1.19)	1.48	0.23
Ellie was a good listener	4.10 (0.77)	3.56 (0.98)	3.94*	0.61
Ellie has appropriate body language	3.85 (0.85)	3.84 (.86)	0.05	0.01
Ellie was sensitive to my body language	3.36 (0.72)	3.13 (0.86)	1.87	0.29
I would recommend Ellie to a friend	3.72 (1.10)	3.47 (1.03)	1.52	0.24
System Usability	74.37 (13.63)	68.68 (12.05)	3.24*	0.44
Rapport	80.71 (12.10)	75.43 (11.71)	3.28*	0.44

Table 4. *Rapport scores in the three conditions.*

Face-to-face	WoZ	AI
74.42 (4.89)	80.71 (12.10)	75.43 (11.71)

7. CONCLUSIONS

The results of this first evaluation are promising. In terms of subjective experience, participants reported willingness to disclose, willingness to recommend and general satisfaction with both the WoZ and AI versions of the system. In terms of rapport, participants reported feelings comparable to a face-to-face interview. Unexpectedly, participants felt more rapport when interacting with the WoZ system than they did in face-to-face interviews. One possible explanation for this effect is that people are more comfortable revealing sensitive information to computers than face-to-face interviewers (Weisband and Kiesler, 1996; Lucas et al, 2014), though this will require further study. As expected, the current version of SimSensei does not perform as well as human wizards. This is reflected in significantly lower ratings of rapport and system usability. Participants also felt that the AI-controlled Ellie was less sensitive to their own body language and often produced inappropriate nonverbal behaviors. It should also be noted that our current evaluation focused on subjective ratings and needs to be bolstered by other more objective measures. Such analyses are a central focus of current work. Nonetheless, the overall results are promising and suggest the system is already effective in eliciting positive use-intentions. One key advantage of our SimSensei Kiosk framework over a human interviewer is the implicit replicability and consistency of the spoken questions and accompanying gestures. This standardization of the stimuli allows a more detailed analysis of user responses to precisely delivered interview questions. Another potential advantage is that recent results suggest that virtual humans can reduce stress and fear associated with the perception of being judged and thereby lower emotional barriers to disclosing information (Hart et al, 2013; Lucas et al, 2014). Realizing this vision will require a careful and strategic design of the virtual human's behavior in future efforts.

The SimSensei system has been further refined via funding from a set of clinical projects. In one ongoing project, U.S. military service members were given a full battery of psychological tests and interviewed by the automatic SimSensei (AI) interviewer prior to a combat deployment in Afghanistan. This unit is still serving on their deployment at the time of this writing and will return in December 2014 for a post deployment round of SimSensei testing and will be studied at 6 months and one year post deployment as well. The primary goal is to determine if both verbal and non-verbal behaviors at pre and post deployment can predict mental health status in an objective fashion. In an upcoming study, the SimSensei clinical interviewer will also be used as part of the assessment package within a clinical trial testing VR Exposure Therapy for the treatment of PTSD due to military sexual trauma. The SimSensei interview will be conducted at pre-, mid- and post-treatment in order to compare results with a sample whose mental health status is expected to improve over the course of treatment. A video of a user interacting with the AI SimSensei VH agent is available here: http://youtu.be/Yw1c5h_p6Dc

Acknowledgments. The effort described here is supported by DARPA under contract W911NF-04-D-0005 and the U.S. Army. Any opinion, content or information presented does not necessarily reflect the position or the policy of the United States Government, and no official endorsement should be inferred.

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Cravings in a virtual reality room paired with chocolate predict eating disorder risk

R S Astur[1], A W Carew[1], A Palmisano[1], B E Deaton[1], F Kuhney[1], R Niezrecki[1], M Santos[2]

[1]Department of Psychology, University of Connecticut, 406 Babbidge Road, Unit 1020, Storrs, CT, USA

[2]Connecticut Childrens Medical Center, Hartford, CT, USA

robert.astur@uconn.edu, andrew.carew@uconn.edu, alexandra.palmisano@uconn.edu, bonnie.deaton@uconn.edu, franchesca.kuhney@uconn.edu, rachel.niezrecki@uconn.edu, msantos@connecticutchildrens.org

ABSTRACT

Pavlovian conditioning is a major factor in drug and food addictions. Previously, we have shown in humans that we can reliably establish a conditioned place preference to a virtual reality (VR) room that is paired with real life food reward. We examined whether the strength of this conditioned place preference is related to eating disorder risk. 31 food-restricted female undergraduates were recruited and placed into a VR environment consisting of 2 visually distinct rooms connected by a hallway. Participants underwent 6 pairing sessions in which they were locked into one of the two rooms and explored the VR environment. Room A was paired with real-life M&Ms for 3 sessions, and Room B was paired with no food for 3 sessions. After the conditioning, a test session was given in which participants were given free access to the entire VR environment with no food present. Additionally, participants completed a standard assessment of eating disorder risk, the Eating Attitudes Test (EAT-26). We observed a conditioned place preference only for the participants who were in the top 50 percentile for hunger. Self-reported hunger rating was significantly correlated with amount of time in the room paired with food. In regards to the eating attitudes, we observed that the higher the eating disorder risk, as evidenced by higher scores on the dieting subscale, and as evidenced by higher total risk scores, the lower they rated the room paired with no food. This suggests a unique conflict whereby stimuli that are not food associated are rated as less enjoyable, particularly the higher the risk for an eating disorder. Hence, novel measures and associations from a brief conditioning paradigm predict eating disorder risk and may suggest some implicit conflicts and processes involved in people with eating disorders. Future studies will examine people with eating disorders more directly as well as will examine whether these measures can direct treatment strategies and predict treatment success.

1. INTRODUCTION

The conditioned place preference (CPP) task is a standard behavioral model widely used in nonhuman research to assess the rewarding and aversive effects of a substance. Although the task differs along several dimensions, generally it involves two compartments joined by a connecting tunnel. The two compartments are contextually distinct across many modalities including visual, auditory, tactile and olfactory cues. Procedurally, the animal is confined to one of the two compartments and is given a rewarding substance for a fixed amount of time. In a separate session, the animal is confined to the other contextually distinct compartment and receives a placebo substance for an equal amount of time. To strengthen the relationship between context and presence or absence of the rewarding stimulus, these pairings are often repeated. Following the pairing sessions, a test session is given in which the animal receives unrestricted access to both compartments without any reward or placebo. It is frequently observed that animals demonstrate a strong preference for the room in which the reward was previously paired despite the reward no longer being present (van der Kooy et. al, 1983). While this preference can be seen with a variety of drugs (Mattson et. al, 2003), it can also be seen with natural reinforcers such as food, water, copulatory opportunity, and opportunity for social interaction (Tzschentke, 1998). Pavlovian conditioning is the most widely accepted explanation for the CPP. Essentially, the context paired with the reinforcer becomes a conditioned stimulus that predicts the presence of the reinforcer (CS+). Conversely, conditioned place aversions can also be observed if a context is paired with an aversive stimulus (Prus et. al, 2009).

While food is typically considered a rewarding stimulus, eating disorders, such as Anorexia Nervosa (AN), have been associated with food avoidance resulting in relentless restrictive eating and severe emaciation (Frank et.al, 2012). Disorders like AN and Bulimia Nervosa (BN) pose a unique challenge for clinicians since they are complex, of undetermined etiology, and are sometimes theorized as being culturally pressured by ideals of thinness (Strober,1995). However, while culture and societal pressures may exist, it is now recognized that a biological basis to these disorders may exist (Bulik, 2004). Moreover, eating disorders are believed to have commonalities of dysfunction in brain areas associated with reward. For example, data from animal models of eating disorders have demonstrated alterations in dopamine, acetylcholine, serotonin, and opioid reward systems (Avena et. al, 2011).

We are interested in whether the CPP task can be useful to predict eating disorder risk as well as treatment success. We previously have demonstrated that food-deprived undergraduates display a strong CPP for a room previously paired with chocolate reward using both implicit as well as explicit measures (Astur et al, in press).

Our current aim is to determine whether there is an association between eating disorder risk and CPP strength. We hypothesize that the higher the eating disorder risk, the less the amount of time spent in the chocolate-paired room on the test day.

2. METHOD

2.1 *Participants*

Thirty-one University of Connecticut female undergraduates (avg. age = 19.3 yrs; SD = 1.57) were recruited from Introductory Psychology classes for this experiment via the university participant pool. Participants were required to abstain from eating for six hours prior to the experiment. It was also required that participants were willing to eat chocolate for the purposes of this experiment. Participants received class credit for their participation. Approval for this study was obtained from the University of Connecticut Institutional Review Board.

2.2 *Apparatus*

An IBM-compatible computer with a SVGA color monitor was used for testing. Participants navigated through the virtual environments by manipulating a joystick. A speaker connected to the computer was used to provide auditory feedback to the participants. A Med Associates Inc. ENV-203IR pellet dispenser was used to dispense M&Ms into a tray for the participant to consume.

2.3 *Procedure*

Food-deprived participants arrived at approximately 9:30 A.M., and consent was obtained. The participant was seated at a computer and was guided through a brief tutorial on how to interact with the virtual environment using a joystick. Participants received a 90 second practice session in which they were placed into an empty VR room. Throughout the practice session and in the experimental sessions, to encourage exploration, a coin appeared periodically in random locations, and participants were required to locate and collide with the coin. Additionally, an M&M was dispensed during the practice session, and participants were instructed that throughout the experiment, they are to eat the M&Ms as they are dispensed. Participants were allowed to ask questions at any time.

After finishing the practice session, each participant completed six six-minute experimental pairing sessions in a virtual environment. A short, 1- minute break followed each session. The environment consisted of two visually distinct rooms connected by a neutral hallway (see Fig 1). In each of the six experimental sessions, the participants were confined into one of the two rooms and were to explore the environment using the joystick.. One room was paired with real M&Ms for three sessions while the opposite room was paired with no food for three sessions. The room paired with M&Ms and the orders of the pairing sessions were counterbalanced. One M&M was dispensed periodically into a cup next to the participant during the M&M sessions, and the participant was instructed to eat the M&Ms as they were dispensed. Between 50-60 M&Ms total were dispensed during conditioning, which is approximately the amount in a regular 47.9g single size bag of M&Ms. After all six sessions were completed, a 10-min break was given before the test session.

For the test session, participants were placed in the same virtual environment and started in the neutral hallway. They had access to both rooms for the entire six minute session. M&Ms were not dispensed on the test day. After the test, participants were given a survey. Questions asked which of the two rooms they preferred, how much they enjoyed each room on a scale of 0-100, and how much they enjoy chocolate on a scale of 0-100. Lastly, participants were also asked to complete Eating Attitude Test – 26 (EAT-26; Garner et al, 1982), which is a brief questionnaire designed to assess eating disorder risk. The EAT-26 consists of 3 subtests, Dieting, Bulimia, and Oral control, which are combined to obtain a Total score. After filling this out, participants were then offered snacks, debriefed, and dismissed.

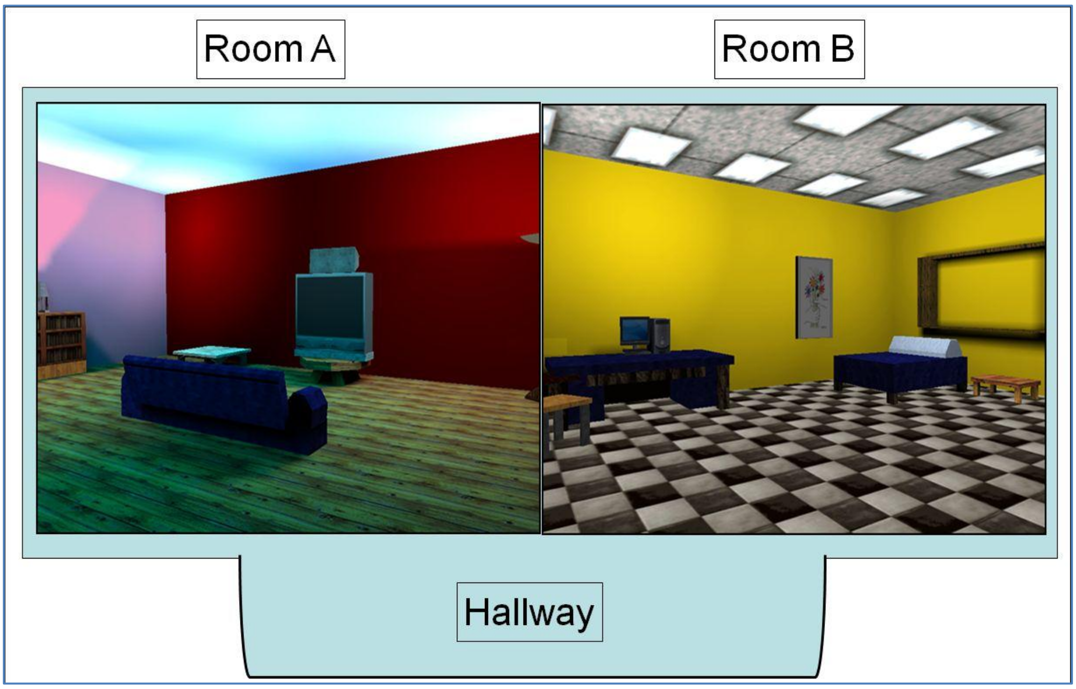

Figure 1A. *Both rooms were identical in shape, but contained different items, colors, patterns, etc.*

Sample Testing for one participant						
Day 1 Conditioning Sessions						**Day 2 Test Session**
Session 1	Session 2	Session 3	Session 4	Session 5	Session 6	Test Session
Room A	Room B	Room B	Room A	Room B	Room A	Free Access
No Food	M&Ms	M&Ms	No Food	M&Ms	No Food	No Food

Figure 1B. *A sample testing order for one participant. Across participants, testing order and M&M/Room pairings was counterbalanced.*

3. RESULTS

Data analysis: Times spent in rooms on the test day were compared using a paired Student's t-test. Correlations between variables in the CPP task and with the EAT-26 were calculated using Pearson bivariate correlations. An alpha level of 0.05 was used in all analyses.

During the test session, participants did not display a CPP, in that there is no significant difference between dwell time in the room previously paired with M&Ms compared to the No Food room, $t(30) = 0.74$, $p > 0.1$. However, anecdotally, some participants seemed reluctant to each the M&Ms as the experiment progressed, and we hypothesized that they were becoming satiated with M&Ms during the conditioning sessions which occur immediately prior to the test session. Additionally, we know from previous experiments in our lab that hunger is necessary for a place preference to be evident (Astur, et al, in press). To address this, we performed a median split on self-reported hunger level. When examining participants in the upper 50% of hunger ratings, we see a significant CPP in that participants spent 70% of their time in the M&M room compared to 30% of their time in the no food room, $t(14) = 3.31$, $p = 0.005$, Figure 2. There is no significant place preference for those in the bottom 50% of hunger ratings, $t(15) = 1.36$, $p > 0.1$.

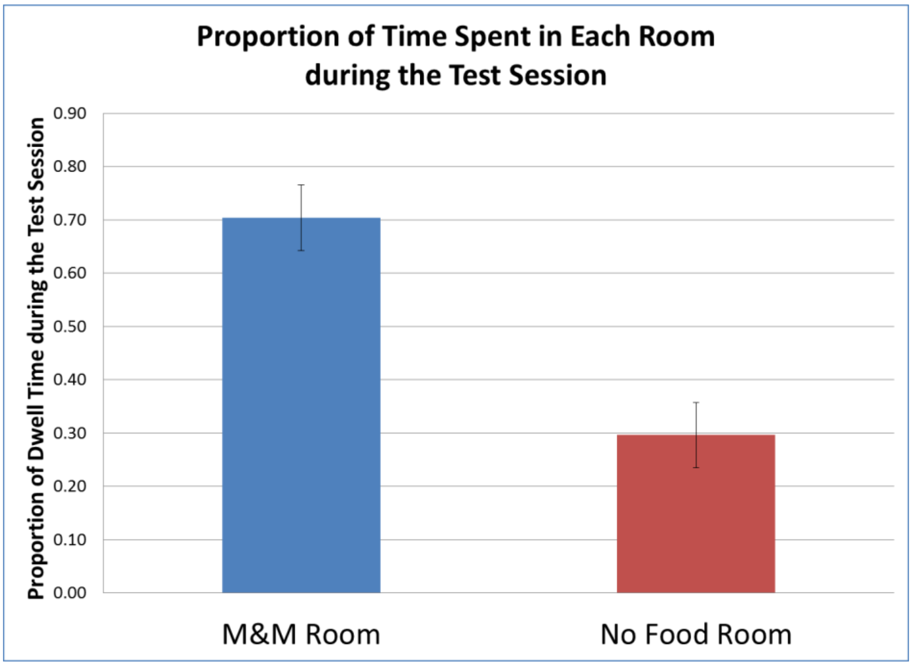

Figure 2. *There was a significant place preference for the room that was previously paired with M&Ms (p = 0.005) for the people who were in the upper 50 percentile for self-reported hunger levels. For those who were in the bottom 50 percentile for hunger, there is no significant place preference.*

To examine the relation between the place preference and EAT-26, we conducted a number of Pearson bivariate correlations. We observed that there was a significant positive correlation between reported hunger level and amount of time spent in the M&M room on the test day, $r = 0.52$, $p < 0.01$. Additionally, there was a significant positive correlation between the explicit rating of how much participants liked the M&M room with the amount of time spent in the M&M room on the test day, $r = 0.39$, $p < 0.05$. In regards to the EAT-26, we observed that there was a significant negative correlation with the EAT-Diet score and the explicit rating of how much the participants liked the non-M&M room, $r = -0.53$, $p < 0.01$. Similarly, there was a significant negative correlation with the EAT-Total score and the explicit rating of how much the participants liked the non-M&M room, $r = -0.47$, $p < 0.01$. That is, the higher their eating disorder risk (as determined by EAT-Diet and EAT-Total), the lower they rated the room that never contained any M&Ms. Lastly, the higher their eating disorder risk, as determined by EAT-Oral Control, the higher they rated that they enjoyed chocolate, $r = 0.44$, $p < 0.05$.

4. CONCLUSIONS

The results indicate that as a group, there is no place preference evident on the test day. Previously, we reported that we were able to elicit strong place preferences in hungry undergraduates (Astur et al, in press). However, in the current paradigm, the conditioning and the test session are on the same day, whereas our previous paradigm was a 2-day study, with the conditioning and the test session being on separate days. Accordingly, whereas participants were food-restricted prior to starting the current experiment, by the time they were given the test session, they had already consumed approximately 50 M&Ms, and numerous participants were less than enthusiastic about consuming M&Ms at this stage in the experiment. Hence, given that our test session was after eating these M&Ms, many participants were not hungry when the test session was presented, and we previously have shown that if participants are not hungry, there will be no place preference. To address this, we performed a median split on self-reported hunger levels, and we observed that those in the upper 50% of hunger show a strong and significant place preference, whereas those in the bottom 50% do not show any place preference. Collectively, these data again indicate the importance of hunger in observing a place preference to food in female undergraduates.

In fact, when we conducted a number of correlations, we also observed that the hungrier that participants reported that they were, the stronger the place preference that they displayed on the test session. Again, this supports the idea that hunger is a critical factor in observing a conditioned place preference for food. Additionally, the higher the amount of time in the M&M room on the test day, the higher participants rated that room, suggesting that implicit measure and explicit measures of place preference are tapping into the same or similar constructs.

In regards to the eating attitudes, we observed that the higher the eating disorder risk, as evidenced by higher scores on the dieting subscale, and as evidenced by higher overall risk scores, the lower they rated the room paired with no food. This is an intriguing finding in that there is no relation between eating disorder risk and the rating of the room that contained M&Ms. Rather, these significant negative correlations suggest that the room that does not contain food has some negative valance about it, particularly to people with higher risk for eating disorders. It may be that because this room is never paired with a rewarding food, it takes on aversive properties, perhaps because of frustration with the inability to obtain food when in this room. Alternatively, it could be that there is a rewarding process underlying abstaining or controlling food intake, and this process is removed or greatly diminished when in the no food room; accordingly, it takes on aversive qualities. Lastly, it was observed that the higher their eating disorder risk as evidenced by the oral control subscale, the higher that participants rated their enjoyment of chocolate. Again, this is interesting in that it again suggests an internal conflict that some participants are engaging in control of their food intake, and yet, they rate chocolate more favorably than those who do not engage in such oral control. Perhaps this type of oral control involves chocolate being a rare and restricted food item, and hence, it becomes more desirable. Future studies might aim to decipher this by inquiring about frequency and quantity of chocolate consumed.

In this study, we recruited undergraduates without any specific restrictions besides the necessity to eat chocolate. Of our 31 females, there were 5 who had scores on the EAT-26 that would suggest that they were at risk for an eating disorder, and follow-up assessment would be necessary to corroborate and characterize this risk. Hence it is possible that we actually were testing two distinct populations in our study (1) those with an unhealthy relationship with food; (2) those with a healthy relationship with food. And, it could be that these 5 at-risk participants were disproportionately influencing our correlations. Our future studies will specifically target individuals at either high risk or low risk for eating disorders, so that we can obtain a better understanding of how these two groups display preferences for contexts where rewarding food is present. Hopefully, this will launch new avenues of research aimed at understanding reinforcement, addiction, relevant brain structures, and the contributing factors.

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Analysis of arm movement strategy in virtual catching task

T Yamaguchi[1], N Ishiura[2], P Richard[3], D A Foloppe[4], F Veaux[5], M Dinomais[6], S Nguyen[7]

[1,2] Department of Applied Electronics, Tokyo University of Science, 6-3-1, Niijuku, Katsushika-ku, Tokyo, JAPAN

[3,4,6,7]Laboratoire Angevin de Recherche en Ingénierie des Systèmes (LARIS - UPRES EA7315), 62 avenue Notre Dame du Lac, Université d'Angers, Angers, FRANCE

[6]Faculté de Médecine, Département de Médecine Physique et de Réadaptation Pédiatrique, Université d'Angers, Angers, FRANCE

[5,6,7]Centre les Capucins, Département de Médecine Physique et de Rééducation Pédiatrique, Angers, FRANCE

[1]*tk-ymgch@te.noda.tus.ac.jp*,[3]*paul.richard@uni-angers.fr*, [4]*foloppe.deborah@univ-angers.fr*,[6]*mickael.dinomais@c3rf-angers.asso.fr*, [7]*synguyen@chu-angers.fr*

ABSTRACT

In this paper, we explored how the arm movement pattern as well as the related strategy of the children with Cerebral Palsy (CP) and the healthy children can be changed in the virtual catching task on a previously proposed rehabilitation system. We recruited 50 healthy children from elementary school, and 3 children with CP as subjects to classify their arm movement pattern/strategy. As a result of the classification, we identified three arm movement stages: *Initial position*, *Reaching path*, and *Waving form*, as well as movement pattern strategy under each movement stage. Based on the classified pattern, we compared the differences in the time series changes of movement strategy between healthy children and the children with CP. The results show there is a significant difference in the strategy of arm movements in the *Initial position* between healthy and CP children.

1. INTRODUCTION

1.1 Cerebral Palsy Disease

Cerebral Palsy (CP) 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 the early childhood as a difficulty to use aside of the body (hemiparesis). Motor deficits encompass difficulty in planning and executing movement.

Physical therapy is proposed to children with CP to help them to grow and physically develop as well as possible. Traditional approach of physical rehabilitation focuses on muscular strength and proposes repetitively simple and uncontextualized movement. However, such therapies are of little interest to children and offers limited functional value in daily living, affecting their motivation to continue the therapeutic activities (Halton, 2009; Schmidt and Lee, 2005). The constraint-induced movement therapy (CIMT) have been developed to improve movement patterns and to maintain the range of the affected arm and leg joints. This approach is often used to improve upper limb function (Hoare et al, 2007). In this therapy, impaired people are encouraged to use their affected hand by restricting the unaffected hand and asking for intensive movement with the impaired upper limb. However, having the unimpaired arm blocked for long periods of time can generate frustration in the child and might not be applicable in a long-term rehabilitation program. Thus, more child-friendly approaches are needed during the neuro-development of children with CP.

1.2 Upper-Body Interactive Rehabilitation System for Children with Cerebral Palsy

The field of Virtual Reality (VR) has grown dramatically as an emerging tool showing a great potential for use in physical medicine and rehabilitation (e.g., Berger-Vachon et al, 2006; Le Gall et al, 2008). VR system has a capability to achieve rehabilitative goals through the use of real-time feedback as well as adaptive strategy and/or difficulty (Burdea, 2003; Cikajlo and Matjacic, 2009; Rose et al, 2000), and several studies have shown hopeful results but few researches focus on cerebral palsy (CP) (for review see Rahman, Rahman and Shaheen, 2011). In the same vein, we have begun a technical and clinical project aiming to create an efficient VR-based game to improve the upper limb function of children with CP by encouraging them to use their affected hand as well as to improve their movement and motor control of the limb (Yamaguchi et al, 2012).

1.2.1 Virtual Rehabilitation System. Our system for rehabilitation propose a catching task (see Figure 1). Standing upright in front of a screen monitor, the user can control the upper limbs of a displayed avatar by moving their own upper limbs. A Microsoft Kinect™ sensor was placed at the bottom of the screen, to capture positional data of the user's left/right hands, wrists, elbows, and shoulders in 3D space. Our system maps the data to the movements of the avatar's limbs. The movements of the avatar's hands are represented on a circle displayed at the center of the screen. Positional data is converted to 2D positional data and rendered in real time to provide visual feedback to reduce motor errors. The sample rate of the Kinect sensor was simulated in the catching task. The sample rate data were collected while the catching task is played 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.

1.2.2 Catching Task. In the proposed catching task, virtual objects appear randomly at the border of screen, one by one, and move toward the center. The user controls the virtual limbs of the avatar in an attempt to touch a virtual object moving around within the virtual space. The application emulates multiple properties of the virtual object, including direction and velocity of movement, size or shape. If the user catches one object before it arrives at the center, he or she wins one point. The system supports two interaction techniques: (a) One hand (only the left or right hand is used) and, (b) both hands (left/right hands are used simultaneously or separately). 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).

1.2.3 Control/Display Ratio. The avatar is mapped directly to the user's movements with a 1:1 ratio. In addition, it is possible to increase/decrease the amplitude of the virtual movement (display) compared to the real movement (control). The control/display ratio can give children more or fewer degrees of freedom in the virtual environment with their non-paretic or paretic arm.

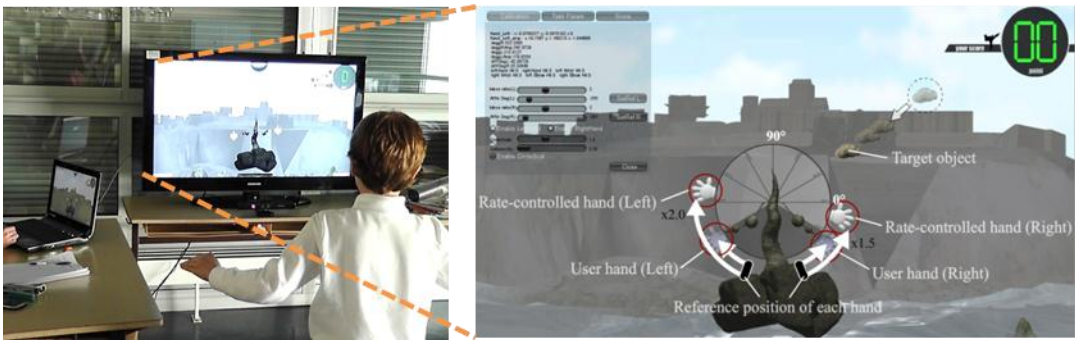

Figure 1. *An experimental setting of rehabilitation application (Left), and Screenshot of rehabilitation application – Control/Display Ratio is set up for both hands: 2.0 for the left hand, and 1.5 for the right hand. Both the left/right hand avatar disappear when the task begins. The degree of the object's direction is rotated counter-clockwise (Right).*

1.3 Arm Movement Pattern and Strategy

In our previous studies, we assessed the effectiveness of the proposed system as described above focusing on the possibility to increase the amplitude of the virtual movement (display) compared to the real movement (control).The first study conducted with 12 university students (mean age = 24.3 years, SD= 3.3) showed that the control/display ratio of the prototype application was related to task difficulty, movement strategy, and user motivation. The virtual catching task provides rehabilitation by reproducing the upper limbs movements. We also found that the user could be challenged, excited, and motivated to perform the task with a Control/Display (C/D) of 1.5 and 2.0 (Yamaguchi et al, 2012). Concerning the C/D 1.0 condition, the users commented that the movement was realistic, natural and simulated. This result indicates that user motivation as well as user's arm movement pattern can be changed with different C/D ratios, that is, with task difficulty. Pasch et al. (2008) have identified two strategies while gamers are playing the Nintendo Wii Boxing game: *Game* and *Simulation*, as well as the related movement patterns with these strategies. With the first strategy of *Game,* gamers aim for a high score, resulting in two different movement patterns: (1) low punch amplitude and corresponding low physical

Proc. 10th Intl Conf. Disability, Virtual Reality & Associated Technologies
Gothenburg, Sweden, 2–4 Sept. 2014
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intensity, (2) high punch amplitude and high physical intensity. In the second strategy of *Simulation*, gamers appear to imitate real-life boxing.The results indicate that there is a relationship between arm movement pattern and its strategy based on task difficulty. In fact, there have been previous research works about the relationship between ability/level of learning and game difficulty (Greitzer et al, 2007; Hunicke et al, 2004). However, it is not clear how movement strategy could be changed corresponding to the movement pattern. Moreover, there is little research about the movement pattern based on time series data.The purpose of this study is to explore how the arm movement and the related strategy can be changed in the virtual catching task. We recruited elementary school children and children with CP to analyze their arm movement pattern.

2. EXPERIMENT WITH HEALTHY CHILDREN

2.1 Participants

Fifty healthy children, aged from 6 to 11 years were studied. All were recruited from the same French primary school, in a rural area. All the parents gave informed consent to participate in this study, according to the guidelines of the Institutional Review Board of Northwestern University Medical School. There were 25 girls and 25 boys. Their mean age was 8.79 years (SD = 1.39). There were 3 left handed children, 9 ambidextrous and 38 right handed children.

2.2 Apparatus

One Kinect sensor was employed for the virtual catching task. The Unity3D platform was used for graphic rendering. All children were placed in a standing position at a distance of about 3 meters from the Kinect sensor.

The equipmentsused for the VR-based game was a Toshiba laptop running on Windows 7 (Processor: Intel Core i7 720QM, RAM: 4GB), a 1920x1080 pixels 42" Samsung screen (to improve immersion and provide real-life scale) and a Kinect as motion sensor.

2.3 Outcome Measures

Quantitative and qualitative data were collected during this experiment, as follows: i) The performance on the VR-based game was measured by the system in the three conditions, namely *dominant hand* (DH), *non-dominant hand* (NDH) and *independent hand* (IH, either dominant or non-dominant hand, or both); ii) The children’s motion was recorded by the system in real time; iii) and as qualitative data, children’s behavior during interaction with our VR-game was categorized by analyzing video recordings of the game sessions.

2.4 Task Procedure

Children were asked to stand upright at a distance of about 3 meters from the screen and were given a brief phase of familiarization. They were encouraged to move around while looking at the avatar and given additional explanations about the interaction without any specifications that could constrain their movements in order to observe the most natural motor behavior. Children were required to perform the virtual catching task as described in 1.2.2 by setting the focus hands used to catch target objects. The focus hands consist of three game sessions as following, in randomized order:

(i) DH session including 52 objects to touch with the dominant hand;

(ii) NDH session including 52 objects to touch the non-dominant hand;

(iii) IH session including 52 objects to touch with any hand (i.e., dominant *and/or* non dominant).

2.5 Results

2.5.1 Classification of arm movement pattern. Firstly we reviewed video recordings that were taken during the experiment to explore the behavior of the participants during the experimental task. Based on the result of the review process, we found a number of feature pattern of arm movements. We assumed that children chose their movement pattern based on their physical limitations. In order to automatically extract their movement patterns, we carried out rough pattern classification from the video recordings of the experimental task.

As a result from the classification using video recording data, we categorized the arm movement pattern into three behavior stages:

- *Initial position*: the initial arm position at the beginning of a virtual catching task and when catching a virtual object.
- *Reaching path*: the path of arm movement when reaching a target virtual object.

- *Waving form*: the form of arm waving when reaching a target virtual object.

In each of the three stages, we divided into some movement patterns of the ways the children moved their arms.

2.5.2 The movement pattern in "Initial position (IP)"stage. Initial position stage is defined as the position at the start of the catching task. The *Initial position* stage consists of three patterns: **IP1** is the pattern that occurs when the child keeps the arms at the position of the previously caught object, **IP2** is when the arms return to a fixed position, and **IP3** is when the child puts his or her arms down (Figure 2).

As described in *3.4*, subjects were required to catch 52 objects in each session. We analyzed the video recordings and counted the number of time each of the three patterns in the *Initial position* were observed. This process is applied to all tasks in each session.

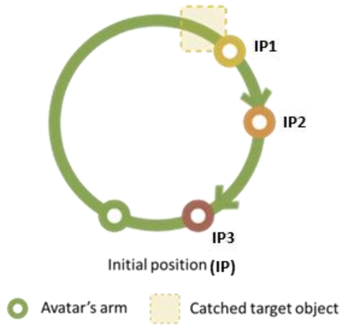

Figure 2. *Classified arm movement patterns stage: Initial position*

2.5.3 The movement pattern in "Reaching path" stage.Reaching path stage is the stage when the child is making a strategy on how to catch the target object. The *Reaching path* stage consists of two patterns: **RP1** is the pattern when the child moves his or her arms by the shortest distance to the object, and **RP2** is the pattern when they move the arms in the reverse direction to reach the target object. Table 3 shows the details of the pattern classification (Figure 3). We performed similar video analysis and counted the number of occurrences of each of the *Reaching path* patterns in all the catching tasks.

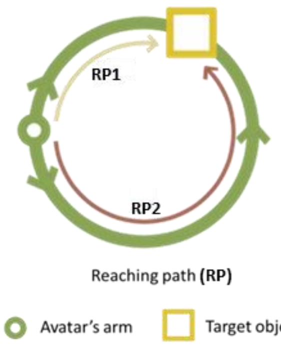

Figure 3. *Classified arm movement patterns stage: Reaching path*

2.5.4 The movement pattern in "Waving form (WF)" stage.Waving form stage is a form of waving arm to catch target objects. The *Waving form* consists of two patterns: **WF1** is the pattern of large swinging movements, and **WF2** is the pattern of small swinging movements. We performed similar video analysis and counted the number of occurrences of each of the *Waving form* patterns in all the catching tasks.

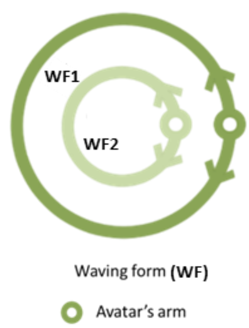

Figure 4. *Classified arm movement patterns stage: Waving form*

3. EXPERIMENT WITH CP CHILDREN

The following section describes the experiment with children diagnosed with CP. The previous section outlines the selected participants, the materials, the procedure and the data analysis of the first study. As a next step, we conducted experiment targeting children with CP. Cerebral palsy may affect children's posture, balance and ability to move, communicate, eat, and sleep. Children with cerebral palsy may have specific learning difficulties, motor planning difficulties such as organization and sequencing, perceptual difficulties and language difficulties. They may have uncontrolled or unpredictable movements. Their muscles can be stiff, weak or tight and in some cases they may have shaky movements.

3.1 Participants

We have recruited 3 children with CP in this study. There were two female with left dominant hands, and one male participant with right dominant hand. Their mean age was 7 years (SD = 2.08).

3.2 Apparatus

We employed exactly the same apparatus as we used in the experiment for healthy children as described in 3.2.

3.3 Task Procedure

Children with CP were asked to perform the virtual catching task in the same way as described in 3.4 for several times in 10 days, during the morning and afternoon of the day. In this study, we added one more focus hand condition: BOTH condition (BH) when the children used *both* left and right hands simultaneously, and INDEPENDENT condition (IH) when the dominant hand *and/or* non dominant hand could be used separately.

3.4 Results and Discussion

We determined the pattern incidence rate in each stage from the data of 50 healthy children as well as from the data of three children with CP in10 days. The pattern incidence rate was calculated using an equation as follows:

$$Pattern\ incidence\ rate[\%] = \frac{The\ number\ of\ occurrence\ of\ the\ pattern*100}{The\ sum\ of\ number\ of\ occurence\ of\ all\ pattern\ in\ the\ category} \qquad (1)$$

3.4.1 Time series changes of movement pattern distribution of children with CP. Figure 5 illustrates the time series changes of pattern incidence rate of each movement pattern in *Initial position* stage. *Initial position* stage consists of three patterns as described above. Each bar chart shows the average ratio of movement pattern of three children with CP**.**

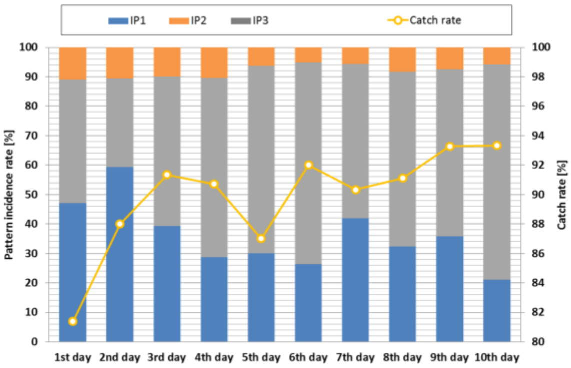

Figure 5. *Time series changes of averaged pattern incidence rate of each movement pattern in* Initial position *stage (The focus hand is LEFT).*

A chi-square test was performed to compare the ratio of movement pattern between CP 1st day and CP 10th day data, and we found a significant trend (Chi-square = 19.9299, *df* = 2, *p* value < 0.001). The pattern IP3 has a trend to be increased with the catch rate (successful rate of the virtual catching task). As for the pattern IP1 and IP2, there was a trend to be decreased over time. From the result of the significant trend, we assumed that the children with CP have a tendency to select a strategy that has a low physical workload to increase the performance of the catching task.

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Figure 6 illustrates the time series changes of pattern incidence rate of each movement pattern in *Reaching path* stage. *Reaching path* stage consists of two patterns. Each bar chart indicates the average ratio of movement pattern of three children with CP.

The bar chart on the 1st day includes 80% (SD = 3.54) of pattern RP1 and 20% (SD = 1.13) of pattern RP2.These patterns did not dramatically change on the 10th day with RP1 at 77% (SD = 2.74) and RP2 at 23% (SD = 1.88). A chi-square test was conducted to compare the ratio of movement pattern between CP on the 1st day and on the 10th day and no significant difference was found (Chi-square = 0.0478, $df = 1$, p value = 0.827). It can be concluded that movement strategy of CP children has not changed after10 days. However, RP1 pattern was mostly selected by CP children.

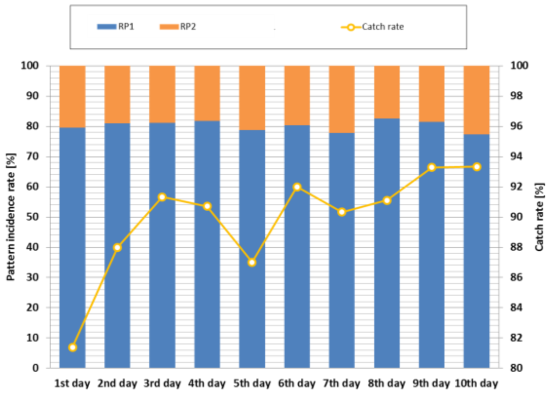

Figure 6. *Time series changes of averaged pattern incidence rate of each movement pattern in* Reaching path *stage(the focus hand is LEFT).*

Figure 7 shows the time series changes of pattern incidence rate of each movement pattern in *Waving form* stage. *Waving form* stage consists of two patterns. The bar chart on the 1st day shows 49% (SD = 4.82) of pattern WF1 and 51% (SD = 7.38) of pattern WF2, and the patterns were not dramatically changed on the 10th day with WF1 at 58% (SD = 5.81) and WF2 at 42% (SD = 8.81). A chi-square test was performed to compare the ratio of movement pattern between the 1st day and the 10th day and there was no statistically significant difference (Chi-square = 1.1937, $df = 1$, $p = 0.2746$). CP's movement strategy did not change after 10 days.

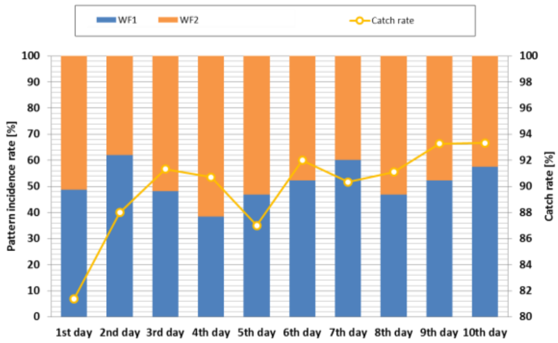

Figure 7. *Time series changes of averaged pattern incidence rate of each movement pattern in* Waving form *stage (the focus hand is LEFT).*

*3.4.2 Comparison of the movement pattern distribution.*Figure 8 illustrates the comparison between the movement pattern distribution of the children with CP and that of healthy children. The first two columns on the left represent the average ratio of movement pattern of the CP children on the 1st and the 10th day. The rightmost column indicates the average ratio for the healthy children.

A chi-square test was performed to compare the ratio of movement pattern between CP on the 10th day and healthy children data and there was a significant difference (Chi-square = 45.9485, $df = 2$, $p < 0.001$). We previously expected that both CP children and healthy children would eventually have the same strategy of opting for a low physical workload. However, the data shows that they are different. Healthy children prefer IP1 movement pattern. With IP1, the healthy children can optimize their reaching distance to a target object so that

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they can touch the next object easily with less arm movement. CP patients changed their strategy to IP3 instead, opting to a fixed position to return their hands. We assume that it was hard for them to keep the hands at the same position where they catch a target object since they have difficulty moving their arm.

Figure 9 illustrates the comparison of the movement pattern distribution of the children with CP and that of healthy children. The first two columns on the left represent the average ratio of movement children with CP on the 1st and the 10th day. The rightmost column indicates the average ratio for the healthy children. Pattern RP1 was the most selected movement strategy by the healthy children as well as the CP children.

A chi-square test was performed to compare the ratio of movement pattern between CP children on the 10th day and healthy children data, and there was no significant trend (Chi-squared = 0.017, df = 1, p = 0.8964). The ratio of movement patterns of the patients did not change from the 1st day of the training to the last day, as previously described in *4.4.1*. The result indicates that the *Reaching path* stage does not affect the physical condition as well as the achievement rate of the applied task.

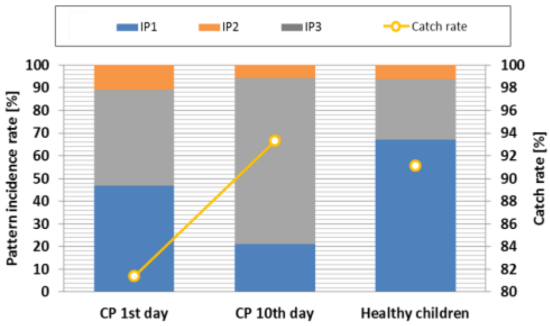

Figure 8. *Comparison of each pattern incidence rate of healthy students and patients in* Initial position *stage (The focus hand is LEFT).*

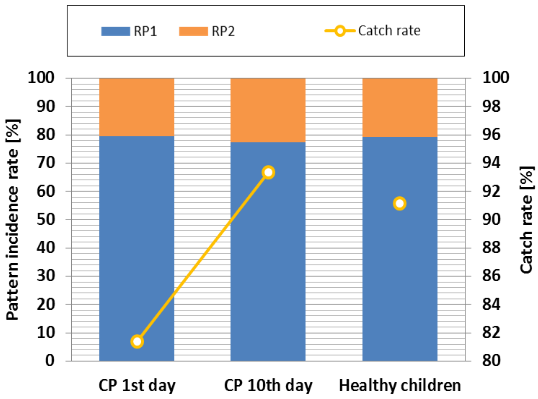

Figure 9. *Comparison of each pattern incidence rate of healthy students and patients in* Reaching path *stage (The focus hand is LEFT).*

Figure 10 illustrates the comparison between the movement pattern distribution of the children with CP and that of healthy children. The first two columns on the left indicate the average ratio of movement pattern of the CP children. The rightmost column shows the average ratio for the healthy children. A chi-square test was performed to compare the ratio of movement pattern between CP children on the10th day and healthy children. There was no significant trend (Chi-squared = 0.7247, df = 1, p = 0.3946).The pattern of the CP children did not change from the 1st day of the training to the last day as described in *4.4.1*. The result indicates that the *Waving form* stage does not affect physical condition as well as achievement rate of the applied task.

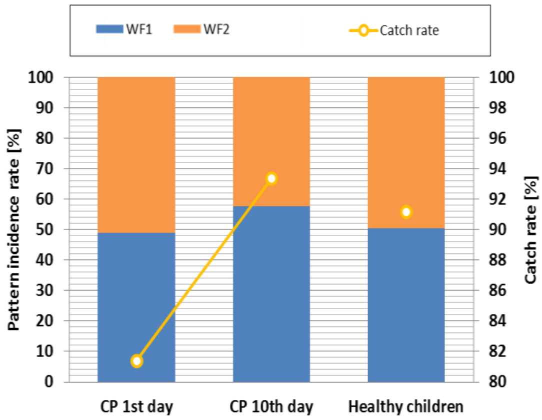

Figure 10. *Comparison of each pattern incidence rate of healthy students and patients in* Waving form *stage (The focus hand is LEFT).*

4. CONCLUSION

Cerebral palsy refers to various motor impairments caused by damage to the central nervous system during foetal development. Our VR-based game is been designed to encourage children to use their affected limb. In this paper, we explore how the arm movement pattern as well as the related strategy of children with Cerebral palsy and healthy children can be changed in the virtual catching task on the previously proposed rehabilitation system. We analyzed video recordings during the virtual catching task for both healthy children and CP children over 10 days and categorized arm movement stages into: *Initial position*, *Reaching path*, and *Waving form*, as well as movement pattern strategy under each movement stage.

For the CP children's data, we found that movement strategy in *Initial position* stage was changed at the last day of training from the pattern IP1on the 1st day where the child keeps the arms at the position of the previously caught object to pattern IP3 where they put his/her arms down. The most selected movement pattern in *Reaching path* stage was pattern RP1 when the child moves the arms by the shortest distance to the object, and the trend was not changed at the last day. For *Waving form* stage, the most selected movement pattern was pattern WF1 of large swinging movements, and the trend was not changed at the last day.

For the healthy children's data, the most selected movement pattern in *Initial position* was pattern IP1 where the arms are kept at the position of the previously caught object. This is a different trend from the CP children. The most selected movement pattern in *Reaching path* stage and in *Waving form* for healthy children were the same as that of the CP children.

As a future works, we plan to analyze the relationship between movement pattern/strategy and their motivation changes during rehabilitation task. We also plan to extend our system to enable dynamically adjusting a task difficulty based on patient movement pattern/strategy.

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Functional improvement of hemiparetic upper limb after a virtual reality-based intervention with a tabletop system and tangible objects

R Lloréns[1,2], C Colomer[2], E Noé[2], M Ortega[1], M Alcañiz[1,3]

[1]Instituto Interuniversitario de Investigación en Bioingeniería y Tecnología Orientada al Ser Humano, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, SPAIN

[2]Servicio de Neurorrehabilitación de los Hospitales NISA Valencia al Mar y Sevilla Aljarafe. Fundación Hospitales NISA. Valencia, SPAIN

[3]Ciber, Fisiopatología Obesidad y Nutrición, CB06/03 Instituto de Salud Carlos III, Av. Sos Baynat s/n, Univesity of Jaume I, 12071 Castellón, SPAIN

rllorens@labhuman.com

[1]*www.labhuman.com*, [2]*www.neurorhb.com*

ABSTRACT

Rehabilitation of the hemiparetic upper limb after stroke is a common challenge for neurorehabilitation units. Recent advances in behavioural neuroscience and neuroimaging techniques have provided current insights of brain plasticity mechanisms that support the functional improvement after an injury to the brain. Different interventions have provided evidence of improvement associated to cortical reorganization. Initial studies report the benefits of virtual reality interventions to recreate enriched and controlled environments that promote brain plasticity mechanisms. This paper presents a novel virtual reality-based tabletop system that focuses on the motor learning principles to promote functional improvement of the hemiparetic upper limb in chronic individuals with stroke. The system allows users to perform a set of exercises that train different movements and skills interacting with or without tangible objects. A preliminary study to determine the clinical effectiveness and acceptance of a virtual reality-based intervention is provided.

1. INTRODUCTION

Upper extremity hemiparesis is the most common disability after stroke (Gresham et al, 1995). An injury to the brain involving the primary motor cortex and/or the corticospinal tract usually affect the voluntary control of the contralateral skeletal musculature. The result, depending on the extent and location of the lesion, is mainly paresis of the contralateral limbs. The mechanism of motor recovery after stroke may involve reorganization of the surviving networks (Takenobu et al, 2013), which take over functions that previously involved the affected tissues. Neuroplasticity, evidenced as the underlying neural mechanism of this reorganization, occurs as an endogenous process during the first weeks after the event due to different neural mechanisms (resolution of the diaschisis, rewiring, etc.) (Dancause et al, 2011). After this period of time, plasticity, though possible, must be driven externally. Even though this period is continuously being extended, it is commonly assumed that spontaneous recovery takes place within the first six months (Dobkin, 2004). However, thirty to sixty-six percent of subjects with stroke present functional disabilities related with the upper extremities after six months since the onset (Kwakkel et al, 2003; Stoykov et al, 2009). Thus, rehabilitation interventions are needed to maximize the functionality of stroke survivors in order to improve their self-dependence and wellbeing. There is no standardized protocol for upper limb rehabilitation after stroke. Throughout the years, different interventions have been presented, such as constraint-induced movement therapy (Corbetta et al, 2010; Wolf et al, 2010), mirror therapy (Invernizzi et al, 2013; Radajewska et al, 2013), or robotic therapy (Takahashi et al, 2008). Nowadays, there is evidence that physiological and anatomical changes are driven, among other factors, by sensory stimulation and skill acquisition (Nudo, 2006). Significant functional and structural changes have been observed in all sensory and motor areas as a result of the experience (Butefisch et al, 2000; Kleim et al, 2002). Nevertheless, reorganization is not driven by mere repetition but it only occurs when the experience implies learning (Dancause et al, 2011). Motor cortical plasticity is therefore learning or skill-dependent, and not simply use-dependent (Nudo, 2006; Grefkes et al, 2014). Consequently, motor rehabilitation should focus on driving plasticity by experiences that mean a challenge for the motor skills of the patients. In connection with this, Virtual Reality (VR) is a specially interesting research field since it allows to recreate computer-generated environments and provide customized experiences involving different sensory channels, commonly sight, hearing, and/or touch. The motivation of using VR in motor rehabilitation after a brain lesion is the administration of specific experiences to drive cortical reorganization that supports the reacquisition of motor skills. There is an increasing number of studies using VR for rehabilitation with promising results (Gil-Gomez et al, 2011; Laver et al, 2012; Llorens et al, 2012), most of them focusing on upper limb rehabilitation (Cameirao et al, 2012; Subramanian et al, 2013; Turolla et al, 2013). Even though the neural basis that supports VR interventions has been vaguely studied, initial studies report promising results (Jang et al, 2003; Saleh et al, 2011; Orihuela-Espina et al, 2013).

The objective of this study is twofold: to present a novel VR-based tabletop system for the rehabilitation of the hemiparetic arm that allows hemiparetic individuals to interact with a set of exercises designed to promote the motor learning mechanisms with their own movements or using tangible objects; and to determine the clinical effectiveness and acceptance of an experimental intervention using the system in a sample of chronic hemiparetic individuals post-stroke.

2. METHODS

2.1 Participants

All the stroke survivors who were attending a rehabilitation program and presented a residual hemiparesis from the lesion were candidates to participate in the study. Inclusion criteria were 1) age ≥ 35 and < 65 years old; 2) chronicity > 6 months; 3) absence of severe cognitive impairment as defined by Mini-mental state examination (Folstein et al, 1975) cut-off > 23; 4) able to follow instructions as defined by Mississippi Aphasia Screening Test (Romero et al, 2012) ≥ 45; 5) able to move the joints (proximal and distal) as defined by Medical Research Council Scale for Muscle (Paternostro-Sluga et al, 2008) ≥ 2; and 6) no increase or slightly increase in muscle tone as defined by Modified Ashworth Scale < 3. The exclusion criteria were 1) individuals with ataxia or any other cerebellar symptom; 2) orthopedic alterations or pain syndrome of the upper limb; 3) peripheral nerve damage affecting the upper extremities; and 4) individuals whose visual or hearing impairment does not allow possibility of interaction with the system.

2.2 Instrumentation

The VR-based rehabilitation system (UMBRELLA: upper limb rehabilitation lamp) consisted of a projective tabletop system that allowed multitouch interaction with the hands or via manipulation of tangible objects. Essentially, the system consisted of a depth sensor and a projector attached to the upper plane of a rigid frame (Figure 1.a). The sensor and the projector pointed down so that when the frame was placed on a table their field of view overlap on the surface of the table, thus defining an area of interaction (AOI) (Figure 1.b). The system projects a virtual environment (VE) on that area, which reacts according to the users' movements, mimicking the interaction with the real world. A standard computer generated the VE, tracked the movements of the user on the AOI, and modified the VE according to it (Figure 1.c). The hardware used in this experiment consisted of a Kinect™ (Microsoft®, Redmond, WA, USA), a computer Vostro 420 (Dell Inc., Round Rock, TX, USA) equipped with a QuadCore @ 2.83 GHz and 4 GB of RAM, and a LCD projector EB-1720 (EPSON, Suwa, NGN, Japan).

The interaction of the users within the AOI was detected from the depth information of the scene. In each exercise, the required movements of the upper limb segments, fingers, and tangible objects were tracked, and the interaction with the virtual objects was calculated to update the VE (Lloréns et al, 2012).

The exercises developed covered a wide range of hand and arm movements, mostly focusing on the flexion and extension of the elbow and the wrist (Table 1). The interaction with some exercises required tangible objects with different thickness to be grasped and moved by the participants. Exercises covered tasks that were likely to belong to the motor repertory of the participants (previous to the onset) and aimed to maximize the correlation with activities of daily living. Exercises provided audio-visual feedback while performing the task and showed information about the remaining time, the repetitions successfully completed, and the record previously achieved by the participant in the exercise. The difficulty of the exercises was determined by different parameters, which mainly adjusted the required speed, intensity, and accuracy of the movements. Before the intervention, the therapists defined different levels of difficulty of each exercise. When the success rate after a session was higher than 80%, the system automatically increased the level of difficulty. When the success rate was lower than 20%, the system decreased the level of difficulty.

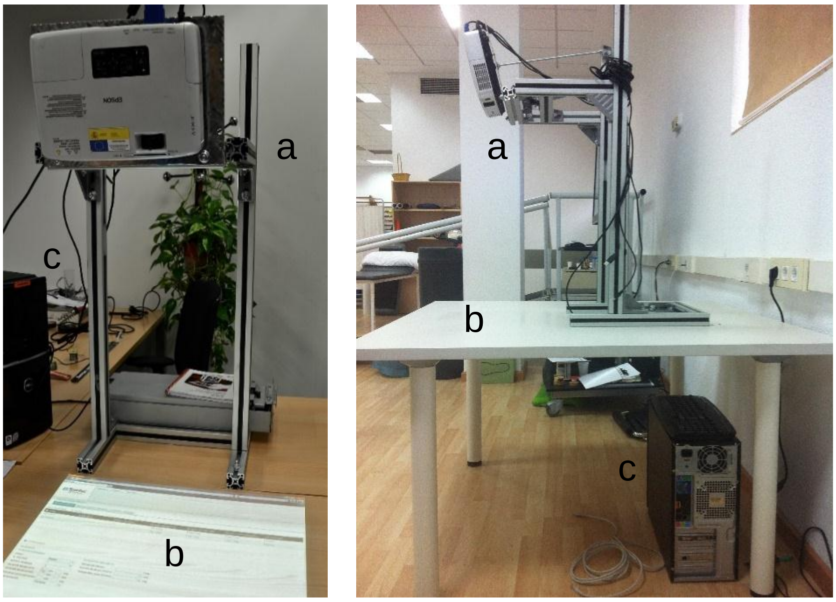


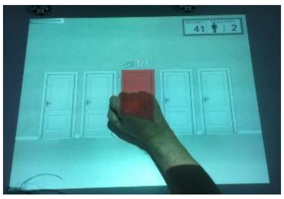
Figure 1. *Prototype of the UMBRELLA system.*

Table 1. *Equivalence of movements and exercises.*

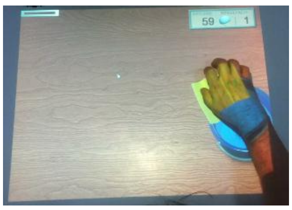
Movement	Exercise
Flexion-extension of the wrist without involving the fingers	To sweep the crumbs from the table (Figure 2.a)
Grasping and flexion-extension of the wrist	To grate (Figure 2.b)
Flexion-extension of the wrist against gravity	To knock on doors (Figure 2.c)
Grasping involving flexion-extension of the elbow and rotation of the shoulders	To cook (Figure 2.d)
Flexion-extension of the metacarpophalangeal-interphalangeal joint	To squeeze a sponge (Figure 2.e)
Tapping	To dial a number (Figure 2.f)
Flexion-extension of the thumb, index, and middle finger	To play piano (Figure 2.g)
Pincer grasping with the thumb and index involving flexion-extension of the elbow and rotation of the shoulders	To buy ítems (Figure 2.h)


(a)


(b)


(c)


(d)


(e)

(f)


(g)

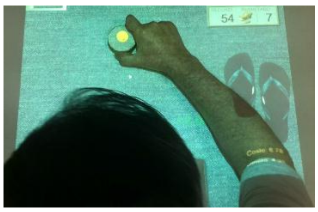

(h)

Figure 2. *Participant interacting with the UMBRELLA system.*

2.3 Intervention

The clinical trial was conducted through the specialized neurorehabilitation service of a large metropolitan hospital. All the participants who agreed to take part in the study and provided an informed consent were included in the clinical trial. Ethical approval for the study was granted by the Institutional Review Board at Hospitales NISA, Spain. An ABA design was chosen to determine the behaviour of the participants while undergoing the conventional therapy, the effect of changing the intervention, and the maintenance of gains after the experimental intervention. Phase A consisted of 30 training sessions of conventional physical therapy intervention, and phase B consisted of 30 sessions of an experimental intervention with the VR-based system. In both phases, the sessions were 45-minute long and were administered with a frequency of three to five days a week. A physical therapist supervised all the training sessions in all the phases. The intensity of both interventions was paired. No robotic therapy, electrotherapy, mirror therapy, motor imagery therapy, or constraint-induced movement therapy were administered during the clinical study.

The conventional physical therapy intervention included passive, active-assisted, and active-resistive joint mobilization, muscle toning (active or active-assisted movement in weightless conditions), strengthening, sensory retraining (Perfetti's method), and manual dexterity exercises. Two two-minute breaks were allowed after 15 and 30 minutes of the beginning of the session. The difficulty of the training was determined by a physical therapist in a previous exploratory session. During the intervention, exercises gradually increased in resistance (weights) and in repetitions. The experimental intervention included the eight exercises described in Table 1 in randomized order. Duration of the exercises was set to five minutes each. Two-minute breaks were allowed after the third and sixth exercise. The difficulty of the experimental intervention was also initially determined in a previous exploratory session, and was automatically adjusted by the VR-based system during the intervention depending on the success rate of each participant within the exercises or by the physical therapist who supervised the sessions.

All the participants were assessed four times along the intervention: 1) at the beginning of the initial phase A (A_i); 2) at the end of the initial phase A, which was the beginning of phase B (B_i); at the end of phase B, which was the beginning of the second phase A (B_f), and at the end of the second phase A (A_f). The assessment protocol evaluated 1) the body structures, with the Modified Ashworth Scale (MAS) (Sloan et al, 1992); 2) the body functions, with a strength test with a dynamometer (ST) (van der Ploeg et al, 1991), the Motricity Index (MI) (Kopp et al, 1997), and the Fugl-Meyer Assessment Scale (FMAS) (Duncan et al, 1983); 3) the body activities, with the Manual Function Test (MFT) (Miyamoto et al, 2009), the Wolf Motor Function (WMF) (Woodbury et al, 2010), the Box and Blocks Test (BBT) (Mathiowetz et al, 1985), and the Nine Hole Peg Test (NHPT) (Oxford Grice et al, 2003); 4) the participation, with the subscales of Quality of Movement and Amount of Use of the Motor Activity Log (MAL-QOM and MAL-AOU, respectively) (Hammer et al, 2010), and 5) the usability of the experimental system, only assessed in B_f, with the System Usability Scale (SUS) (Bullinger et al, 1991), and with four subscales of the Intrinsic Motivation Inventory (IMI) (McAuley et al, 1989).

2.4 Statistical analysis

For each scale and test, scores in all the assessments were compared using repeated measures analyses of variance (ANOVAs). Post-hoc simple contrasts (Bonferroni) were conducted for each significant time main effect to determine the source of the significant difference. The α level was set at 0.05 for all analyses. All analyses were computed with SPSS for Mac, version 15 (SPSS Inc., Chicago, USA).

3. RESULTS

After inclusion/exclusion the final sample consisted of 11 participants. One participant was discharged of the neurorehabilitation program by the Public Healthcare System and dropped out. Consequently, his data are not included in the study. The characteristics of the participants are shown in Table 2.

Repeated measures analyses of variance (ANOVAs) at every assessment of the clinical trial revealed a significant time effect in most of the scales that assessed the body activities (WMF, BBT, and NHPT), and in the participation scale (MAL-QOM and MAL-AOU) (Table 3). With respect to these scales throughout the therapy, post-hoc analysis showed significant improvement after the experimental intervention (from B_i to B_f). However, this improvement was not detected after the previous (from A_i to B_i) or following conventional intervention (from B_f to A_f). No significant differences were detected in either the body structures or functions.

With regards the usability, scores of the SUS (79.58±8.99 from a total score of 100) and the subscales of the IMI (5.46±0.40 from a total score of 7) showed good acceptance of the experimental system.

Table 2. *Characteristics of the participants. Data are expressed in mean ± standard deviation when possible.*

Characteristic	Value
Sex (n,%) *Male* *Female*	 8 (80 %) 2 (20 %)
Age (years)	53.65±17.32
Chronicity (days)	273.90±97.13
Aetiology (n,%) *Haemorrhagic* *Ischemic*	 3 (30%) 7 (70%)
Hemiparesis (n,%) *Right* *Left*	 6 (60%) 4 (40%)

Table 3. *Characteristics of the participants. Data are expressed in mean ± standard deviation when possible. NS: no significance.*:p<0.05. **:p<0.01.*

Measure	Start of phase A (A_i)	Start of phase B (B_i)	End of phase B (B_f)	End of phase A (A_f)	Significance
Modified Ashworth Scale	0.60±0.65	0.60±0.65	0.60±0.65	0.60±0.65	NS
Dynamometer (kg)	31.80±14.64	31.20±14.17	32.80±14.66	32.80±13.73	NS
Motricity Index	74.60±9.08	75.60±8.17	77.80±13.17	77.80±13.17	NS
Fugl-Meyer Assessment Scale	51.00±6.65	51.40±6.06	52.30±6.39	52.40±6.82	NS
Manual Function Test	21.30±4.59	22.10±4.72	22.70±4.64	22.60±4.74	NS
Wolf Motor Function Test (s)	76.22±53.36	77.59±61.75	40.87±20.59	48.22±25.83	Bi>Bf*
Box and Blocks Test (blocks)	19.90±10.39	21.20±11.39	26.60±10.94	25.80±11.74	Ai<Bf** Ai<Af** Bi<Bf** Bi<Af*
Nine Hole Peg Test (s)	53.51±21.95	48.30±20.81	40.74±17.81	42.40±19.10	Ai>Bf** Ai>Af* Bi>Bf* Bi>Af*
Motor Activity Log – Quality of Movement	80.25±30.44	82.90±26.10	100.75±25.65	97.05±19.69	Ai<Bf** Ai<Af* Bi<Bf** Bi<Af**
Motor Activity Log – Amount of use	72.35±38.16	76.35±32.21	98.85±32.06	93.65±33.65	Ai<Bf** Ai<Af** Bi<Bf** Bi<Af**
System Usability Scale	-	-	79.58±8.99	-	-
Intrinsic Motivation Inventory *Interest/enjoyment* *Perceived competence* *Pressure/tension* *Value/usefulness*	-	-	 5.75±0.82 5.27±1.02 1.96±0.60 5.77±0.73	-	-

4. DISCUSSION

The high incidence of hemiparesis after a brain injury and its uncertain prognosis make the rehabilitation of the hemiparetic upper limb a challenge for neurorehabilitation units. In the last decade new therapeutic approaches with proved effectiveness, as robotic-based interventions or constraint-induced movement therapy, have been reported and integrated in the motor rehabilitation protocols. However, the high cost of robotic-based devices and their space requirements limit their purchase to large neurorehabilitation units, and the constraint-induced movement therapy presents a low adherence in most patients (Page et al, 2002). Conventional rehabilitation programs include physical and occupational therapy interventions that can be not very motivating, intensive, or easy to replicate outside the clinical environment. This study analyses the effectiveness of a VR-based intervention in the functional improvement of the hemiparetic upper limb following a stroke. The experimental system is a transportable low-cost solution that provides intensive game-oriented exercises that can be configured to tailor interventions according to each patient's needs. These features are specially interesting since changes in motor cortical maps are only associated with an adaptation of the behavioural demands or skill acquisition, rather than with mere repetition (Nudo, 2006).

The experimental intervention provided improvement in the majority of the scales related to the activity of the hemiparetic upper limb, i.e. the WMFT ($p<0.05$), BBT ($p<0.01$), and NHPT ($p<0.05$), and to the participation, i.e. the MAL-QOM ($p<0.01$) and the MAL-AOU ($p<0.01$), with limited improvement in the body structures and functions. This improvement must be highlighted considering the chronicity of the sample. Interestingly, this fact could also explain the absence of changes in those scales that assessed the body structures and functions, as the muscle tone, the motor index, or the strength of the global mobility of the upper limb as measured by the Fugl-Meyer. Results showed improvement in the timed tests, the WMFT, the BBT, and the NHPT. An increase in the speed of task performance has been associated to greater improvements in chronic stages (Levin et al, 2009). The discrete nature of the MFT (scores of each item have discrete values ranging from 1 to 4) can explain that though the clinical improvements after the treatment, this improvement was not significant. The interaction with tangible objects allowed to recreate functional tasks involving not only proximal movements but also grasping and pincer grips. The specificity of these tasks could explain the maintenance of gains observed weeks after the experimental training.

Interestingly, the clinical improvement was also perceived by the participants, who reported the quantity (MAL-AOU, $p<0.01$) and quality (MAL-QOM, $p<0.01$) of the movement of their hemiparetic arm in the activities of daily living. These results are in accordance with the scores to the subjective questionnaires. The interaction of the participants with the system was successful, as reported by the SUS (usability and robustness) and the IMI (usefulness, competence, enjoyment, and low frustration). This could be promoted by some of the features of the system, such as the interface and the exercises. The ecological validity of the tasks (the exercises were designed to address activities commonly present in the motor repertory of the participants) within a natural interaction framework, both in manual tasks and in activities that required manipulation of tangible objects, could have led the participants to increase their confidence in the performance of activities of daily living, thus influencing the scores of the usefulness and the perceived competence subscales.

These results must be interpreted taken into account the limitations of the study. First, the sample was defined according to the requirements of the system. With regards to the motor domain, even though the VR-based system used a conventional table to remove the gravity (and to project the VE), participants were required to have enough mobility to move their hemiparetic arm by the table. In addition, the technological limitations of the system required the participants to be moderate to high functioning as they needed to robustly grasp objects in order them to be tracked. With regards to the cognitive domain, to understand the objective of the exercises all the participants were required to present a good cognitive condition, as defined by Mini-mental state examination > 23. Second, the sample of the study (n=10) can be considered as a small sample, which can limit the extrapolation of the results. Finally, the design of the study did not include a control group. In spite of this, the high chronicity of the sample (far from the initial stages where spontaneous recovery is assumed to occur) and the absence of remarkable improvements after conventional interventions with paired intensity and number of sessions, support the effectiveness of the intervention.

There is a great body of evidence of the motor improvement in chronic individuals post-stroke after specific interventions involving repetitive and intensive task-oriented exercises (Krakauer, 2006). This could support that VR-based interventions satisfying the motor learning principles may enhance the motor improvement in comparison with conventional interventions (Gil-Gomez et al, 2011; Laver et al, 2012). In addition, it is commonly accepted that the ceiling effect of some interventions can be caused by a physiological adaptation to the treatment. New therapeutic approaches, as the one presented here, can be a possible alternative for the motor rehabilitation of stroke individuals with independence of their chronicity.

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Arm prosthesis simulation on a virtual reality L-shaped workbench display system using a brain computer interface

G Heisenberg[1], Y A Rezaei[2], T Rothdeutsch[2], W Heiden[2]

[1]Faculty of Design - Computer Science - Media, RheinMain University of Applied Sciences, Unter den Eichen 5, 65195 Wiesbaden, GERMANY

[2]Institute of Visual Computing, Bonn-Rhein-Sieg University of Applied Sciences, Grantham-Allee 20, 53757 Sankt Augustin, GERMANY

gernot.heisenberg@hs-rm.de, yashar.abbasalizadeh@smail.inf.h-brs.de, timo.rothdeutsch@smail.inf.h-brs.de, wolfgang.heiden@h-brs.de

[1]www.hs-rm.de, [2]vc.inf.h-brs.de

ABSTRACT

The work being described in this paper is the result of a cooperation project between the Institute of Visual Computing at the Bonn-Rhein-Sieg University of Applied Sciences, Germany and the Laboratory of Biomedical Engineering at the Federal University of Uberlândia, Brazil. The aim of the project is the development of a virtual environment based training simulator which enables for better and faster learning the control of upper limb prostheses. The focus of the paper is the description of the technical setup since learning tutorials still need to be developed as well as a comprehensive evaluation still needs to be carried out.

1. INTRODUCTION

The first prosthetic replacement was reported in the book “Vedas” written in Sanskrit in India, being compiled between 3,500 and 1,800 B.C. (Vanderwerker, 2013). For many centuries, the use of prosthetics was limited only to correct the appearance of the missing human limb by means of wood or metal. Nowadays, not only the appearance and the materials of the prosthetic limbs improved significantly. Since the 1960’s medical research focused on the substitution of the functionality of the missing limb, too.

Usually, arm prostheses with grasping functions consist of an underlying mechanical structure being covered by a polyvinyl chloride (PVC) skin cover which is quite robust and appears more human skin-like than other materials. The connection to the human body is used for control.

This can be done by means of myoelectric signals or even brain-computer interfaces as described in the related work section. However, when using myoelectric signals derived by surface electrodes from either the breast muscles or from the remaining part of the arm, controlling gets complicated. Due to the high weight of the prostheses and the associated pre-stress of the muscles being used, signal processing algorithms usually fail by filtering the noise caused by the pre-stress from the intended signal for controlling the prosthesis. Especially in the beginning, when the prosthesis is new to the patient, this can cause an additional psychological burden. The result is a very flat learning curve for the patient.

However, up to now, learning the control of arm prostheses is possible by the intensive supervision of physiotherapists. Hence, the learning phase is accompanied by high costs, too. Therefore the main motivation for the project being described in this paper was to transfer the first learning steps with the prosthesis into a virtual environment, where the prosthesis itself is represented by a weightless graphical representation. The virtual environment itself would provide the means for aligning the virtual prosthesis with the remaining arm. The assumption was that if the graphical representation is of high quality and both, the remaining arm and the prosthesis, are perfectly aligned, then training would become much easier, especially in the beginning.

However, the simulation does not intend to replace the conventional training which obviously is absolutely crucial. But it would allow for an easier learning experience especially in the beginning when the patient’s psychology shows the highest impact on the success of the training.

This paper is describing early research results. Hence it focuses on the technical description of the used setup and provides the results of a system evaluation with healthy users. The authors of the paper as well as the

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cooperation partners intend to develop appropriate autodidactic learning tutorials for the patient using the virtual reality based prosthesis simulator. In addition a comprehensive user evaluation is planned too.

2. RELATED WORK

Prosthetic limbs can be categorized from different perspectives. For example Disabled-World - an independent Health and Disability news source (Langtree and Langtree, 2013), categorizes prostheses by the relative connection place of the prosthetic limb such as below/above the elbow or the knee. Steven Lam (Lam, 2010) used the functionality criterion to categorize prostheses in three groups: cosmetic, body-powered and externally powered prostheses. Considering the purpose of usage, all prosthetic kinds have their own advantages and disadvantages in terms of costs, appearance, functionality and comfort. Cosmetic prosthetics are the cheapest and lightest kind. Their functionality is very limited and mostly they only have been used for correcting the natural appearance of the human body. On the other hand the body-powered prosthetics have more degrees of movement but at the same time they are more expensive and heavier. In comparison to the previous two kinds, externally powered prosthetics focus more on substituting the natural functionality of missing limbs rather than their appearance. Among this type, myoelectric prosthetics use technology like Electromyography (EMG) (Hiraiwa et al, 1989, Huang et al, 2008, Schultz and Kuiken, 2011) for signal acquisition and lightweight electro-motors and batteries for mimicking the functionality of the missing limb.

However, the externally powered prosthetics are not perfect yet. They are the most expensive kind due to special design, and heavier because of the electro-motors and battery weight. From the functional perspective the externally powered prosthetics are the most preferable kind, but due to the special control system, these prostheses are difficult to learn and use (Takeuchi et al, 2007, Anderson and Bischof, 2012). For controlling them patients need to produce electrical muscle activity by moving one or more special skeletal muscles. This work by itself is an extremely hard and time consuming procedure and needs high mental effort as well as motivation, especially during the initial months of training. By considering the stress which is caused by the prosthesis weight and the uncomfortable feeling around the attachment area, it is evident that the training procedure becomes a hard and long way of learning with a very flat learning curve.

It has been proven that VR/AR-based training systems have got good capabilities to significantly improve training performance of many kinds. In order to understand the distinction between VR and AR, VR (virtual reality) refers to systems where the user is immersed almost totally in the artificial environment and just sees virtual objects. The real world reference frame vanishes in the background. The term AR (augmented reality) refers to systems where the user still sees the real world into which virtual objects are placed. However, in many applications this distinction is not easily to make since in projection based virtual environments the user still sees his own body parts and therefore, per definition, these might not be considered to be true virtual reality environments. This is the reason why a third term MR (mixed reality) was introduced, which combines the former two and tries to bridge between VR and AR by a continuum of mixed application possibilities where either virtual or real world objects are prevalent.

In order to improve the control over the muscular activity and decrease the training time, many researchers proposed different training systems. For instance, (Merians et al, 2002) developed a haptic system called "Rutgers-II ND hand master glove" for hand rehabilitation. Otto Bock HealthCare (Otto-Bock, 2012) devised a commercial product called "Myoboy training suit" for measuring EMG signals to find better electrode settings. (Armiger and Vogelstein, 2008) and (De la Rosa et al, 2008) used a game environment to provide engaging and motivating training sessions for individuals.

Among these training systems, the VR and AR based ones are the most popular which were used for training purposes (Takeuchi et al, 2007; Anderson and Bischof, 2012; Luo et al, 2005a; Luo et al, 2005b; Murray et al, 2006; Cole, 2008; Al-Jumaily and Olivares, 2009; Lamounier et al, 2010; Lamounier et al, 2012). The reason is simply that VR/AR-based training systems provide more realistic and natural feedback about the quality of the patient's interactions with the prosthesis and with the environment, respectively. Contrary to this, haptics-based systems are very limited to motor rehabilitation rather than prosthetic limb rehabilitation, and game-based ones do not provide the natural feedback and interaction of the missing limb..

3. SYSTEM SETUP AND APPLICATION

The main part of the prosthesis simulation system used in this project consists of an L-shaped workbench. It is composed of a 1.71 m high and 1.41 m wide metal frame. Two 0.49 m high and 0.67 m wide projection displays are embedded in that frame, expanding a virtual work volume of about 0.17 m^3 size. Two stereo-projectors project the scene onto the corresponding display screens. Two mirrors are used for reducing the projection distance to the screens (see figure 1).

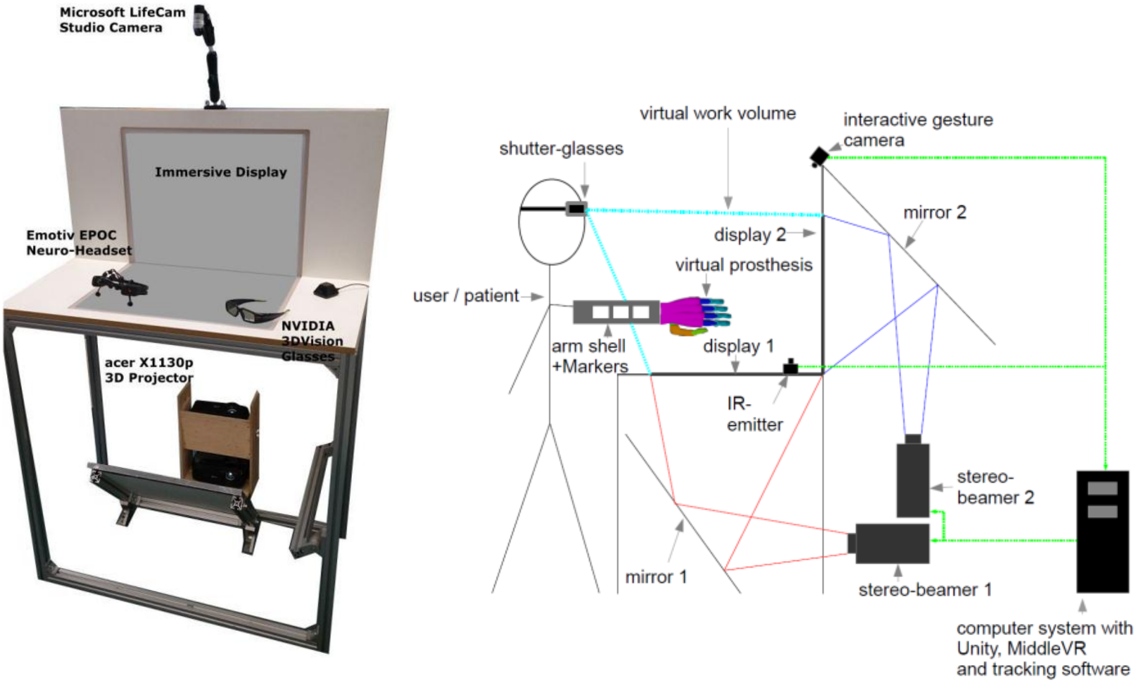

Figure 1. *System setup and L-shaped workbench at the Bonn-Rhein-Sieg University. The right part of the image shows all components being used. The virtual prosthesis model is shown as an extension of the user's arm shell with markers.*

Rendering is implemented by using the Unity game engine (Unity). The choice for Unity was mainly influenced by its huge range of rendering options, animation sequencers and a physics library, detecting and handling object collisions. However, since Unity is not natively supporting stereoscopic output we decided for the additional MiddleVR plugin (I'm in VR, 2013). MiddleVR allows for configuring different display setups as in this case a two orthogonal sided setup of the L-shaped workbench. The setup is stored in a configuration file which again is read and interpreted by Unity. For stereoscopic perception of the images, the NVIDIA 3D Vision set is used, that consists of shutter glasses and an infra-red emitter. The infra-red emitter is responsible for triggering the shutter mode of the 3D stereo glasses which in turn have got an infra-red sensitive sensor. Stereo viewing of the 3D prosthesis model with Unity on the L-shaped workbench is possible now. The remaining issue is the control of the virtual prosthesis model in the virtual environment. For the purpose of aligning it with the user's remaining arm stump the tracking has to be solved by using an arm shell including markers (see figure 2). The arm shell consists of carton on which an AR fiducial marker board is attached for tracking purposes. The board itself is a composition of several single fiducial markers. These markers are recognised by the camera looking down onto the shell from the top frame of the workbench display. The camera is operated by a self-developed tracking application (C++) that recognizes the fiducial markers and computes the translation and orientation (pose) of the entire arm shell. For computation purposes, the C++ tracking application uses the ALVAR (A Library for Virtual and Augmented Reality) (Alvar, 2014) and OpenCV library. ALVAR detects the markers, recognizes them and computes their translation and orientation coordinates by means of a transformation matrix.

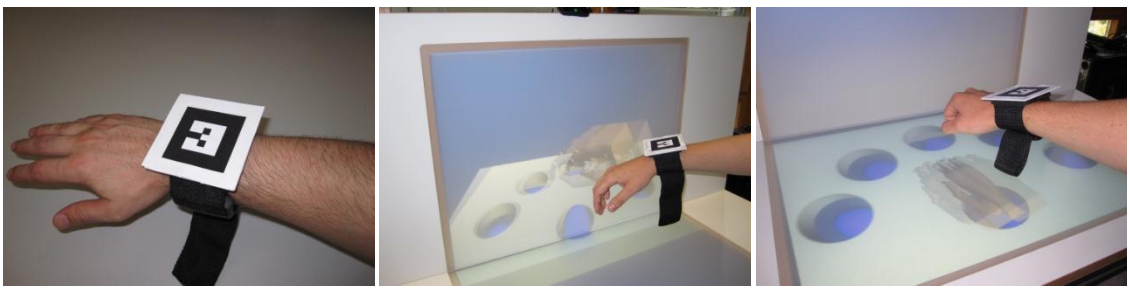

Figure 2. *This simple arm shell is attached to the user's remaining arm stump using fiducial AR markers for tracking.*

After the computation, the pose is sent to the rendering program Unity. Unity now updates the position and orientation of a virtual prosthesis model with respect to the new pose. For doing so, the library ZMQ (ZeroMQ) is used to open up a TCP connection to Unity. ZMQ transfers strings over a network or within a single computer system to any subscribed process. Therefore, we converted the coordinates to string type and ZMQ sends them to localhost since Unity runs on the same graphics PC. However, any IP address can be specified and used by ZMQ. This allows for maximum flexibility if, at a later stage of the project, it will be decided to run the tracking application on a separate machine. As soon as the coordinates are received by the subscriber service of Unity, a script is needed to convert the string data back into a floating point translation and orientation data stream of the arm shell. With the help of this it is possible to update the orientation and position of the virtual prosthesis model represented by a game object in Unity. Since we are importing the tracking data 1:1, the alignment is automatically done and the prosthesis model is located at the same position as the user's arm shell. Hence we are ready to practice controlling the arm prosthesis model which itself follows each movement of the user's remaining arm stump.Figure 3 provides an overview of the software architecture of the project.

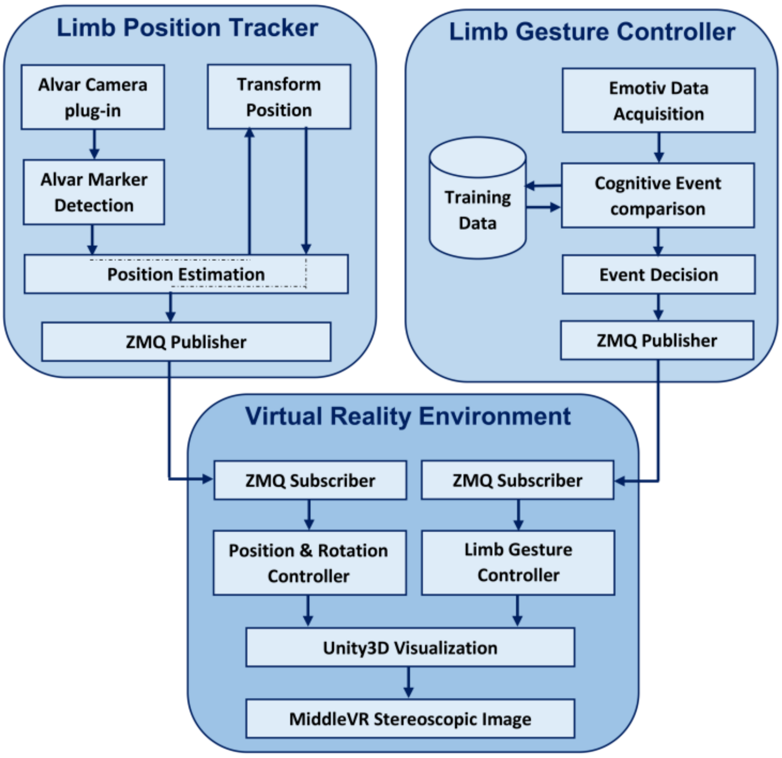

Figure 3. *The Software architecture of the simulator.*

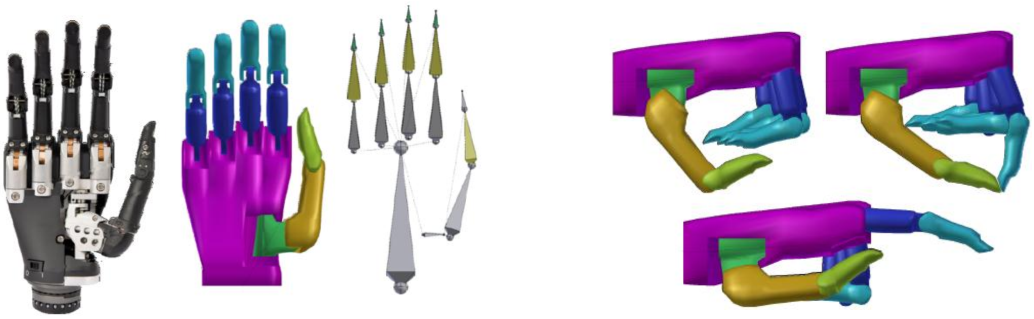

Figure 4. *From right to left, a real prosthesis (i-limb ultra from TouchBionic), a virtual prosthesis model and a kinematic chain created in Blender are shown. Each of the five fingers has got two limbs only. The kinematic model was also created in Blender (left part of the image). The right part of the figure shows the gestures being allowed. These are pointing and two different types of grasping. These gestures can be triggered by using the Emotiv EPOC brain computer interface.*

The virtual prosthesis itself, being modelled in Blender, consists of five two-limbed fingers and a palm of the hand as shown in figure 4. All fingers can be moved separately up to a certain degree since an underlying kinematics model was added in Blender that ensures no child segment can be moved independently from its parents. However, in a first version of the project we did not intend to allow for entire prosthesis control. Instead we implemented animation sequences for grasping and pointing gestures which can be triggered by the user wearing a BCI (brain computer interface) from Emotiv *(*Emotiv, 2013*)* (see figure 4).

The Limb gesture controller is the component that is responsible for the data acquisition from the BCI sensors. It compares the sensor data with training data. Each user was trained to generate at least 4 events (left/right smirk, rise brow and pushing tooth) by using facial expressions. While the output of the Emotiv SDK is an integer in the range from 0 to 100 and also is changing due to other events because of false-positive event decisions, an exponential moving average method was applied to solve this issue. At the end, the selected events are sent over the ZMQ socket to Unity.

4. SYSTEM EVALUATION

In order to evaluate a prosthesis training system, the participants are divided into three groups. The first group uses the actual hardware, the second group uses a remotely controlled training system and the third group uses the proposed training system. While the training takes place, all participants should perform a test to check their performance from start to end of the test period. Then the results of all three groups can be compared to each other. Since the aim of this project is to improve the naturalness of the interaction in the training environment and no individual disabled from upper limb was accessible, we focused on the evaluation of the naturalness of the interaction. In this regard, two test scenarios have been developed, one for model alignment and the other for depth perception.

4.1 Alignment Test

The objective of the alignment test is to find out how the limb model aligns with the remaining physical limb from user perspective while the user interacts with the environment. For this purpose, the following scenario was developed in order to test the alignment:

- The limb model will appear in the pointing gesture.
- 9 targets will appear sequentially in different predefined positions, each one two times.
- The user should point onto the target and shoot a virtual laser beam from index finger through target.
- A proper facial event (smile event) will be used to generate a trigger for shooting the laser beam.
- The laser beam will be visible for 0.2 seconds, which helps the user to correct the model orientation.
- The transformation of the limb model and the target will be used to calculate an error ratio of alignment by the angle between laser beam and the targets.

Table 1. *Target appearance order during the alignment test.*

Target number	1	2	3	4	5	6	7	8	9
Target appearance order	1-9	5-13	3-10	7-15	4-11	14-18	2-6	8-16	12-17

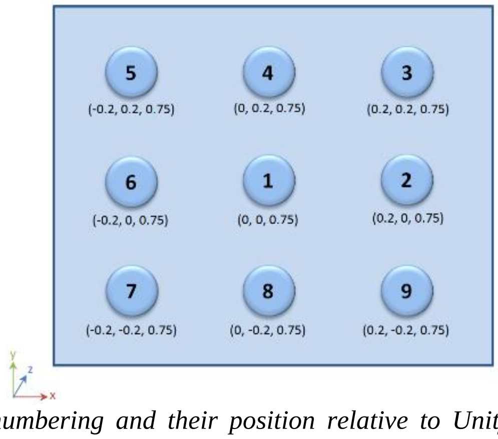

Figure 5. *The targets' numbering and their position relative to Unity3D left hand coordinate system.*

4.2 Alignment Evaluation

The number of participants for this test was 15. The maximum angle illusion is 7.65 degree for target number 2, and the minimum angle illusion 3.97 degree for target number 7. The general observation shows that the targets in the upper right corner have smaller angle illusion whereas the targets in the lower left corner have a larger angle illusion, as shown in figure 7. Considering the point that all participants were right handed, one may conclude that it becomes harder to point correctly to the targets on left side where the eye direction moves away from the limb model. The main issue that has been reported from all participants is that, without having control over the wrist, it is difficult to correct the orientation of the limb when displayed on the lower part of the display.

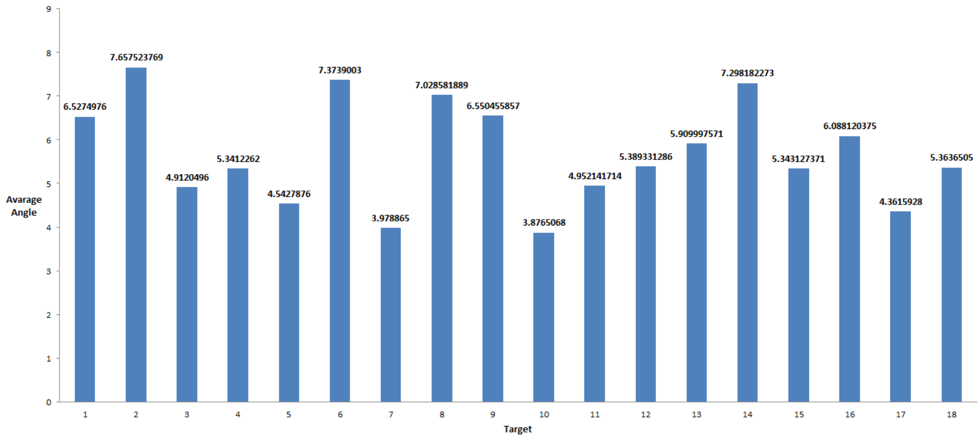

Figure 6. *Total average of the angle illusions for each target in each appearance.*

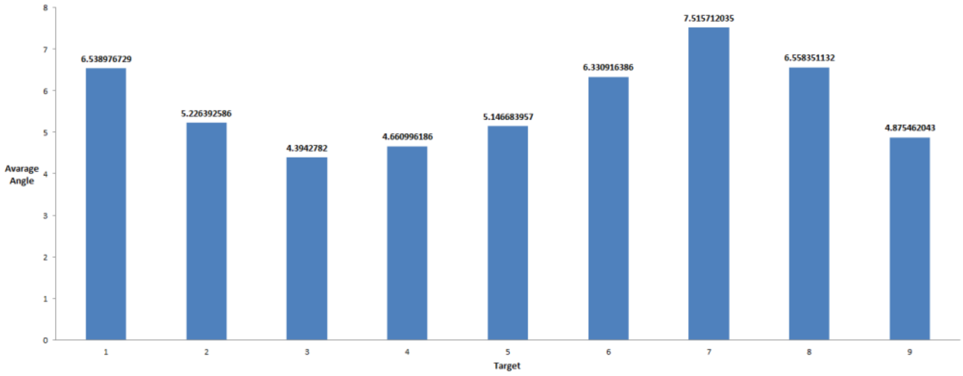

Figure 7. *Total average of the angle illusions for each target.*

Another problem that has manifested itself during the tests, were the fixed position and the orientation of the camera used for rendering. While moving and pointing with the limb model, the users moved body and head, and also rotated their eyes. Since the camera transformation was fix and no tracking was applied to head position and eye orientation, the targets' appearance became increasingly unnatural according to the change in head position and eye orientation.

4.3 Depth Test

The objective of the depth test is to evaluate the aim accuracy for objects in different depths from the user perspective in the training environment. In order to apply this test, the following scenario is created and applied:

- The limb model appears in idle gesture.
- A table with 6 buttons was designed in Blender (a free 3D modelling and animation toolkit) and exported to the Unity3d environment.
- The first button B is an activation button, which is positioned in the center of display and in the nearest depth from the user perspective.
- The other 5 buttons are the targets that will show up in a pre-defined sequential order, each one after the activation button was pressed. They are positioned from left to right by 30 degrees relative to the activation button as shown in figure 8.

- The time between activation and all target hit attempts is recorded.
- The number of failed hit attempts for each target is counted.

Table 2 shows the appearance order of all targets. The user must hit the activation button B after which (according to table 2) the target will show up and the activation button will disappear. After a successful hit, the target will disappear and the activation button will appear again. This procedure continues 3 times for each target until the last target is hit.

Table 2. *The target buttons' appearance order during depth estimation test.*

Target number	1	2	3	4	5
Target appearance order	2-6-12	5-9-14	3-8-15	1-10-13	4-7-11

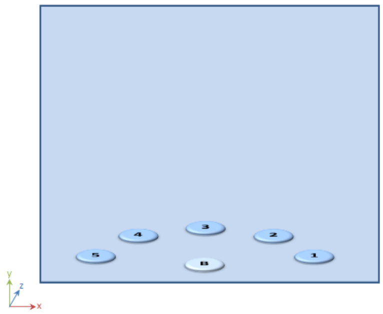

Figure 8. *The target buttons numbering and their position relative to Unity3D left hand coordinate.*

4.4 Depth Evaluation

The test was applied to 15 participants and the result that can be concluded from the test data is almost the same as from the alignment test. The maximum average time before a hit was found for target number 3 with 1.72s. The minimum average time was found for target number 2 with 1.15s, as shown in figures 9 and 10. While it seems obvious from the experimental data that target 3 seems to be most difficult to hit (indicated by the maximum delay time for a hit and the maximum number of misses - see table 3), this finding is not easy to interpret. It might as well result from a perspective issue related to the lower left display region as from a depth estimation problem.

Table 3. *The number of missed hit attempts during depth estimation.*

Target number	1	2	3	4	5
Number of misses	3	0	5	3	2

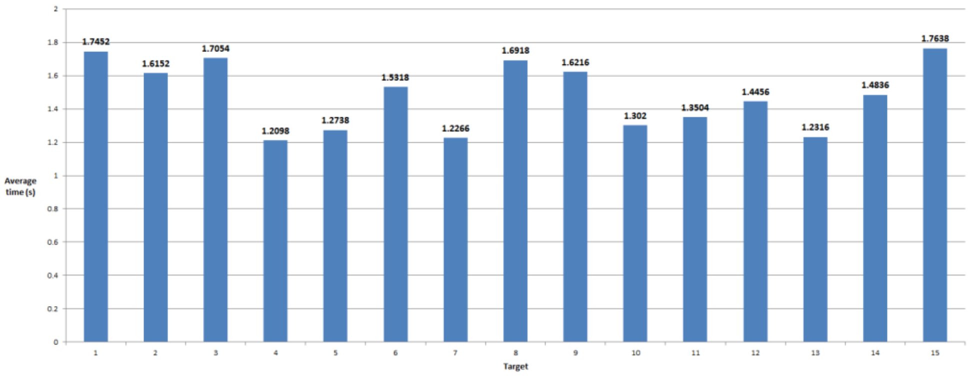

Figure 9. *The average time of each hit action for all target appearances.*

Another important issue that has been observed during depth testing was a significant tracking delay. The marker tracking is a standalone application which sends much less position and orientation data per second over the socket, than data is sent from the tracking component to the visualization component which itself renders at a high frame rate. This is the reason for a clearly observable visualization delay in case of fast limb movements.

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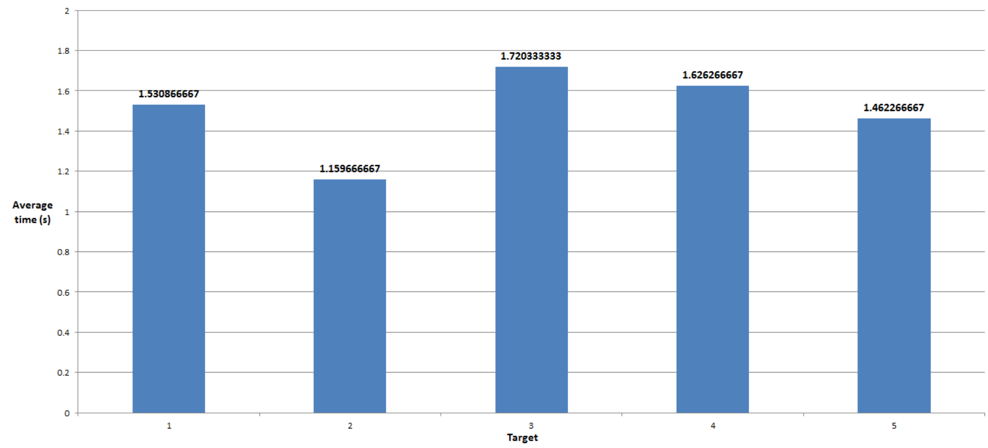

Figure 10. *The total average time of the hit action for all targets.*

6. CONCLUSIONS

With the help of the setup described in section 4, a system was implemented that allows for displaying arm prostheses in a virtual environment being aligned with the remaining arm stump of a user. Hence the technological basis was created for further implementations such as learning tutorials that will potentially support the learning of how to control the prosthesis. It is evident that the quality of that VR training system has to be evaluated by real patients prior to draw important conclusions about the system's usability aspects. However, while working with the system during initial usability tests with healthy users, first feedback was provided.

The first feedback about the system concerned the display system. Even though the frame of the L-shaped workbench display system is made of high-quality welded aluminium profiles (compare figure 1), it was not resistant enough to bending and distortion. The reason for that were recesses impairing the stability. Hence the authors decided to additionally add front and side walls made of reinforced steel profiles. The second feedback about the system concerned the camera tracking. Obviously the camera tracking shows a few real disadvantages such as the constant need for calibration, the need for high camera resolution due to the required high accuracy of the alignment as well as the steep visibility angle, since the camera needs to be mounted on the top of the display frame. Hence, for the future, the authors decided for using a Leap 3D motion controller from the company LeapMotion Inc.. The potential improvements with that tracking device are simply that fiducial makers are not needed anymore and the tracker itself can be easily placed at the bottom side of the display system looking upwards to the remaining arm stump of the user.

As already mentioned, future work will deal with the implementation of electromyographic control. This includes the crucial signal processing algorithms as well as interfacing with the control unit of the prosthesis itself. Furthermore autodidactic learning tutorials will be added. At the moment when this paper is written the authors intend to implement, add and display animated sequences of hand gestures that the user tries to copy. The idea is such that an automatic feedback mode will provide information about the quality of the copied gesture as well as some key performance indicators such as for example time on task. Using Unity 3D as the visualisation platform allows for adding virtual, graspable objects to the virtual scene and rendering the accompanying collision recognition and collision control of the virtual objects with the virtual hand prosthesis. Hence the authors assume that this will significantly improve the psychological acceptance of the virtual prosthesis by the user as well as allow for better control.

Acknowledgements: This work has been supported financially by the Institute of Visual Computing at Bonn-Rhein-Sieg University of Applied Sciences. The authors also would like to acknowledge the project cooperation partner from the Laboratory of Biomedical Engineering at the Federal University of Uberlandia, Brazil for their great input and system evaluation.

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Effect of the Oculus Rift head mounted display on postural stability

P Epure, C Gheorghe, T Nissen, L O Toader, A N Macovei, S S M Nielsen, D J Rosengren Christensen, A L Brooks, E Petersson Brooks

Department for Media Technology, Aalborg University, Niels Bohrs Vej 8, Esbjerg, DENMARK

pepure12@student.aau.dk, cgheor12@student.aau.dk, tniss12@student.aau.dk, ltoade12@student.aau.dk, amacov12@student.aau.dk, ssmn12@student.aau.dk, djrc12@student.aau.dk, tb@create.aau.dk, ep@create.aau.dk

www.en.esbjerg.aau.dk

ABSTRACT

This study explored how a HMD-experienced virtual environment influences physical balance of six balance-impaired adults 59-69 years-of-age, when compared to a control group of eight non-balance-impaired adults, 18-28 years-of-age. The setup included a *Microsoft Kinect* and a self-created balance board controlling a skiing game. Two tests were conducted: full-vision versus blindfolded and HMD versus monitor display. Results were that five of the six balance-impaired adults and six of the eight non-balance-impaired adults showed higher degree of postural stability while using a monitor display. Conclusions are that HMD, used in this context, leads to postural instability.

1. INTRODUCTION

Research exploring Virtual Reality (VR) in healthcare has increased over recent decades with widespread adoption in treatment by professionals evident. A recent development in this field is the Oculus Rift (OR) head mounted display (HMD) developed by the US company Oculus VR™. A main characteristic of OR is its ability to track head movements to allow the user to seamlessly look around the virtual world. The difference between the HMDs mentioned in related work and OR is that the latter blocks the peripheral vision completely. Furthermore, OR offers a field-of-view of 90 degrees for each eye, almost twice as much as anything else on the market, resulting in a fully-immersive 3D experience (Rubin, 2014). For this study, a developer kit OR unit with a resolution of 640 x 800 pixels per eye was used (Boas, 2013).

The primary objective of this study was to investigate how a Virtual Reality Environment (VE), displayed with OR, impacted the physical balance of balance-impaired adults 59-69 years-of-age a control group compared to non-balance-impaired adults 18-28 years-of-age. The setup comprised of (a) a self-created balance board that controls an animated skiing game, especially designed for viewing with OR; (b) *Microsoft Kinect* (camera-based motion sensing device) to measure the angle of sway; and (c) the OR. The system setup and development are detailed in section 3. The following sections (4 and 5) details the two tests conducted with all participants (i.e. both the balance-impaired and non-balance-impaired adults), and the results. In section 6, the strengths and weaknesses of the study are discussed alongside the results and analyses that led to the conclusions presented in the closing section 7. The next section (2) presents related work.

2. RELATED WORK

The aim of this section is to position an understanding about the basics of balance and sensory systems, in context to this study.

2.1 Balance and the Sensory Systems

According to Læssøe (2007), balance is a concept used to define the interaction between different domains (mechanics, physiology, anatomy, sociology, and psychology). The main points of interest are human stability and sensory systems.

Human stability can be defined as the inherent ability of a person to maintain, achieve or restore a state of balance and also includes the sensory and the motor systems of a person. Postural control is a requirement to maintain a variety of postures and activities. As a consequence the control of balance in humans has been acknowledged as three possible broad classes of activities (Pollock et al, 2000, pp. 404), namely:

- the maintenance of a definite posture, for example sitting or standing;
- voluntary movement, for example moving between postures; and
- reaction to an external disturbance, for example a slip or a push

In order to determine the impact of using a HMD related to physical balance, it is necessary to investigate how the sensory systems affect balance. There are three major sensory systems involved in balance and posture: the visual sensory system, which is the main point of interest in this study; the vestibular system; and the somatosensory system (Winter, 1995). The postural control depends on the integration of information received from the proprioceptive, vestibular, and visual sensory systems. It has been showed that extremely low frequencies of sway are best stabilized by vision. Conflicts can also arise between the senses, especially when the visual and/or proprioceptive cues differ from vestibular information (Redfern, Yardley and Bronstein, 2001). Furthermore, Wing, Johannsen and Endo (2011) states that the variability in the rate of change of centre of pressure also increases during upright standing with eyes closed. The explanation is that loss of vision by closing the eyes usually results in increased sway.

2.2 Studies in Rehabilitation with VE Induced through Different HMDs

Different research articles revealed contentious results regarding conflicts between the sensory systems that affect physical balance when exposed to a VE. Peli (1998) studied the potentially harmful effects on the visual system due to HMD use. When investigating functional changes, it was measured if there were any functional changes in binocular vision, accommodation, and resolution when using HMDs compared to monitor display. The results showed that there were no changes in any of the outcomes. The only mentionable difference was that the HMD was less comfortable than CRT monitor (difficulty in focusing and postural discomfort). However, subsequent research revealed the contrary as Wenzel, Castillo and Baker (2002) found that aircraft workers, who used a HMD for training, testified that there were problems such as eyestrain, headache, nausea and dizziness. These problems are usually related to motion sickness, which is necessary to consider in our study (Motion sickness, 2014).

Adaptation to the VE is the key to “postimmersion” symptoms as simulator sickness, since exposure time is significant in order to provoke strong reactions (Cobb and Nichols, 1998, p. 459). Viire (1997) states that many users will not encounter motion sickness symptoms when interacting with a VE. Reed-Jones, Vallis, Reed-Jones, and Trick (2008) indicate that sensory interactions between visually perceived self-motion and static inertial cues from vestibular and proprioceptive sensory system contribute to the development of adaptation symptoms. Sensory interactions initiate postural changes that are observed following VE simulation and are related to the way visual information is used to control posture. Our study investigates if there are postural changes while using OR based on conflicting sensory input.

A number of studies have examined the effect of deliberately inducing a visual-vestibular conflict using a VE (Nishiike et al, 2013; Ohyama et al, 2007; Akiduki et al, 2003). These studies state that conflicts between sensory systems induce postural instability and motion sickness. Their intention was to investigate balance during VE exposure to test the stability during quiet stance under different conditions. It is suggested that the similarity of sway between the VE and the eyes-closed condition is occurring because the visual input from the VE induces greater head movement, thus failing to compensate for the ineffectiveness of the proprioceptive input. Horlings et al. (2009) argue that the lack of peripheral vision in a VE is also influencing the postural control in a negative way.

3. DESIGN AND IMPLEMENTATION

In order to investigate how a VE displayed with OR affects postural control, a system was established to observe, measure, and analyze physical balance. As introduced earlier in this paper, the system consists of: (a) a self-created balance board controlling a skiing game, (b) *Microsoft Kinect* and (c) OR. This section details the making of the bespoke system components.

3.1 Balance Board

The balance board (Fig. 1 and Fig. 2) was created to measure and record the pressure exerted on it.

Components:

1 Spider 8 data logger - A
4 S-type load cells - B
3 connection cables for the load cells - C
8 bolts to secure the load cells - D
2 wood countertops - E
4 wood support blocks - F

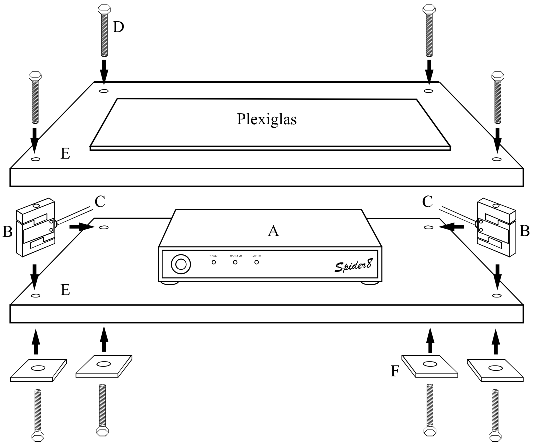

Figure 1. *Setup of the balance board.*

The load cells register the variables made by the bending of the metal foil inside the cell, transforming the mechanical deformation in electrical output signal. To mount the load cells, two pieces of wood countertop were used. A Spider 8 data logger was connected to a PC through a USB/RS232 converter cable in order to communicate with the PC. The load cells were calibrated before each test, to register and control the game. For this study, a program was created in Visual Basic 6 to receive the data from the four load cells and send it through a local User Datagram Protocol (UDP) connection. Lastly, this was mapped to the Unity game engine within which the graphical VE skiing game was programmed.

Figure 2. *Spider 8 data logger (left) and balance board (right).*

3.2 Graphics

In order to stimulate physical balance, we selected to create a skiing game to immerse the participant in a fun and engaging interactive environment. The game play contains a slide where the player has to avoid obstacles and collect cookies in approximately three minutes, by leaning left or right. The main platform used to construct the environment was *Unity*, with imported models from *Google SketchUp Pro 8* and *Autodesk Maya 2014. Unity* also provided some modelling such as icy mountains, the sky and a snowing effect. The slide was modelled in *Autodesk Maya 2014*. (Fig. 3)

3.3 Programming

This section explains how the system components were connected and how they communicate.

As stated in the previous section on graphics, the game was developed in *Unity*, a game engine utilising several different programming languages. The programming languages used for development of our game were *C#* and *JavaScript*. One of the most important factors in the game was to design the in-game movement so it would communicate and respond to the balance board. The skiing-slide was programmed to have 5 lanes where the in-game character could move, each corresponding to a certain pressure value on the balance board. This value was calculated by the following formula; where “a” is the two left sensors on the balance board, and “b” represents the two right ones:

$$-a+b=value$$

As an example, if the participant stands on the balance board and distributes their weight evenly on both sides of the board, the in-game character will remain in the middle lane.

Figure 3. *Snapshots from the game showing the ski-slide (left) and obstacles (right).*

The OR is capable of 360 degrees of head tracking. It was utilized by setting the tracking value proportional to the rotation of the main camera in the game. Therefore, looking around through OR creates the illusion of looking around inside the game.

The *Microsoft Kinect* has no effect on the gameplay; however, it serves an important role along with the balance board in data gathering for the testing sessions. The *Microsoft Kinect* records the spine position and returns values on how much the participant is leaning left and right. After the game ends, it automatically creates a comma-separated values (CSV) file from the data received from the *Microsoft Kinect*. These files can be opened in *Microsoft Excel* and converted to graphs.

4. TESTING

This section describes the different testing sessions that were conducted to investigate the research question; how does a VE, displayed with OR affect postural stability. Four tests were carried out, including: (1) Pre-test – the users were asked to complete a questionnaire (2) a feasibility test, where *Microsoft Kinect* and the balance board was used, (3) full system test, where the whole setup was tried out (balance board, *Microsoft Kinect*, OR and the game), and finally (4) an evaluation study of balance-impaired adults. All the phases of the test were monitored with a video camera in order to back up the results.

A comparison test was performed between adults with impaired balance from the rehabilitation centre at *Sydvestjysk Sygehus Esbjerg*[1] in *Denmark*, and the control group. The reason behind this test was to investigate if there were any noticeable differences between the groups when exposed to a VE. The test was based on information from the physiotherapist at the rehabilitation centre stating that people with impaired balance can have more intense reactions during such a test.

To analyse the data, two types of graphs were created, one for *Microsoft Kinect* data and the other for the balance board data. These graphs were obtained from the CSV files and had two points of reference. The x-axis represents the time interval for each participant (approximately three minutes), while the y-axis represents either the sway-angle registered by the *Microsoft Kinect* or the value of pressure exerted on the balance board. Based on the graphs, patterns were established by evaluating the values, and line fluctuations.

4.1 Pre-test

The participants of the control group were requested to fill out a questionnaire (Healthy balance fitness, n.d.). The survey concerned background information, including questions about their physical condition, their life style, and physical activity.

4.2 Feasibility Test

The feasibility test was split into two phases and took place at *Aalborg University, Esbjerg, Denmark*. The task for the participants from the control group was to perform a set of physical exercises while standing on the balance board. The purpose of this test was to measure the balance of the participants without being exposed to a VE. In the first phase participants had full vision, and in the second they were blindfolded. The reason behind including two phases was to explore how the visual system influences physical balance.

4.3 Full System Test

The full system test was also split in two phases and took place at *Aalborg University, Esbjerg, Denmark*. The participants were the same control group as in the first test. The aim of the full system test was to explore how a VE influences physical balance. The participants had to play the game with the OR and with a monitor display. The two phases of this test were implemented in order to explore the effect of losing peripheral vision.

The participants were split in two groups with the same number of people, to obtain reliable results. The test was semi-randomized, where one group started with the monitor display while the other started with the OR, to avoid training effects on the results (Horlings et al, 2009). Afterwards, a semi-structured interview was conducted to collect feedback regarding the experience.

4.4 Evaluation Study of Balance-impaired Adults

An evaluation study was carried out at *Sydvestjysk Sygehus Esbjerg, Denmark* to compare the data collected from the previous tests. The participants (balance-impaired adults 59-69 years-of-age) performed only the second test. The purpose was to observe if people with impaired balance are more affected by VE than the control group. Six balance-impaired adults were tested, where five of them had a poor heart condition. Due to ethical considerations, physiotherapists, who provided feedback during the session, supervised the test. Afterwards, semi-structured interviews were conducted. The interviews contained different questions: How do you feel about wearing an OR? How was the level of difficulty of the tasks? Did you experience feelings as dizziness or nausea?

5. RESULTS

Based on the interpretation of the graphs and the information from semi-structured interviews and questionnaires, the results from the testing session will be presented in this section.

5.1 Pre-test

The results from the pre-test indicated different life-style aspects. Regarding the alcohol consumption, five out of eight participants drink alcohol on a weekly basis. Only one participant is a smoker and six participants are physically active, while the rest are sedentary. Regarding their physical fitness level, a scale from 1 to 10 was used to describe it, where 1 means poor level and 10 means good level. Table 1 contains all the individual answers from the questionnaire, including an average for each of the aspects.

Table 1. *Individual data indicating life-style aspects.*

Name	Gender	Age	Height (cm)	Weight (kg)	Smoker (y/n)	Alcohol (quant/week)	Sleep (h/night)	Fitness level	Physical exercises
C.	F	22	172	0	No	4-10 drinks	6	6	1-2x/week
A.P.	M	19	185	68	No	4-10 drinks	8	7	3-4x/week
E.T.	M	19	184	68	No	4-10 drinks	8	6	3-4x/week
M.F.	M	28	191	90	No	4-10 drinks	7	4	0x/week
R.M.	M	19	177	69	No	4-10 drinks	8	6	3-4x/week
D.D.	M	18	185	80	Yes	4-10 drinks	7	6	3-4x/week
C.H.	M	22	180	74	No	4-10 drinks	7	6	1-2x/week
M.	M	19	178	78	No	4-10 drinks	7	6	3-4x/week
Avg:	M	20.75	181.5	75.29	No	4-10 drinks	7.25	5.88	3-4x/week

5.2 Feasibility Test

The data from the *Microsoft Kinect* and the balance board indicated that six out of eight participants had more fluctuated graphs while performing the set of tasks blindfolded.

5.3 Full System Test

Based on the graphs, six participants experienced higher degree of sway when being exposed to a VE through the OR, when compared to playing the game on a monitor display.

In Figure 4 and 5, based on the data received from the balance board, the graphs show an example of a participant E.T. playing the game with and without OR. The graphs present more fluctuations of the line when using OR, implying that the participant had difficulties in maintaining balance.

In Figure 6 and 7, based on the data received from *Microsoft Kinect*, the graphs represent the same participant playing the game with and without the OR. Again, the graphs present more fluctuations when playing with OR, signifying that the participant could not maintain a proper postural stability.

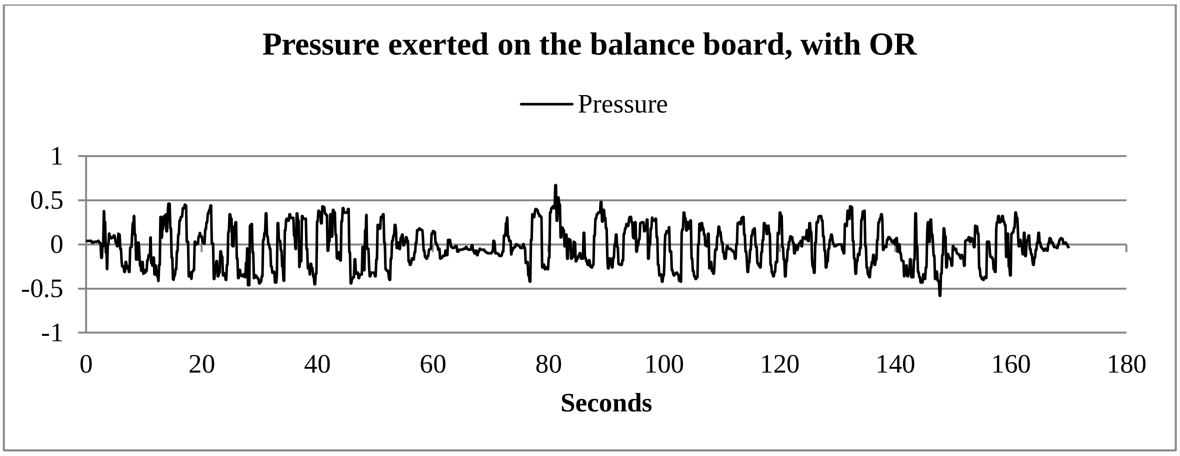

Figure 4. *E.T. performing the game with OR.*

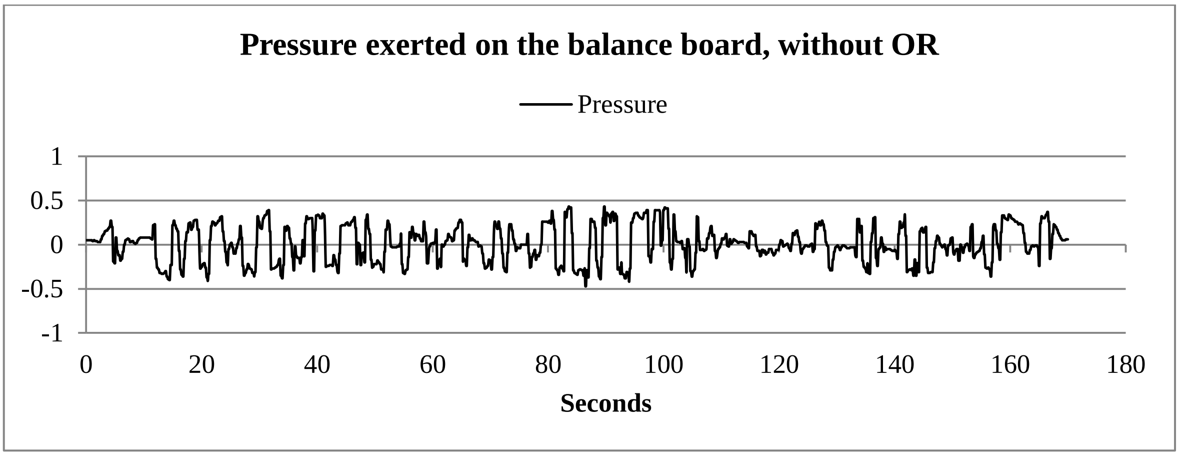

Figure 5. *E.T. performing the game without OR.*

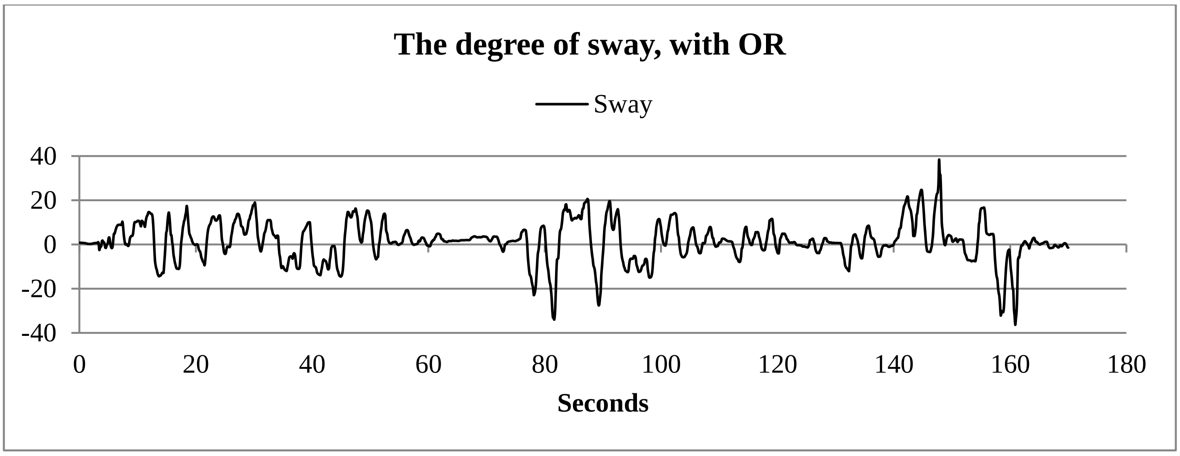

Figure 6. *E.T. performing the game with OR.*

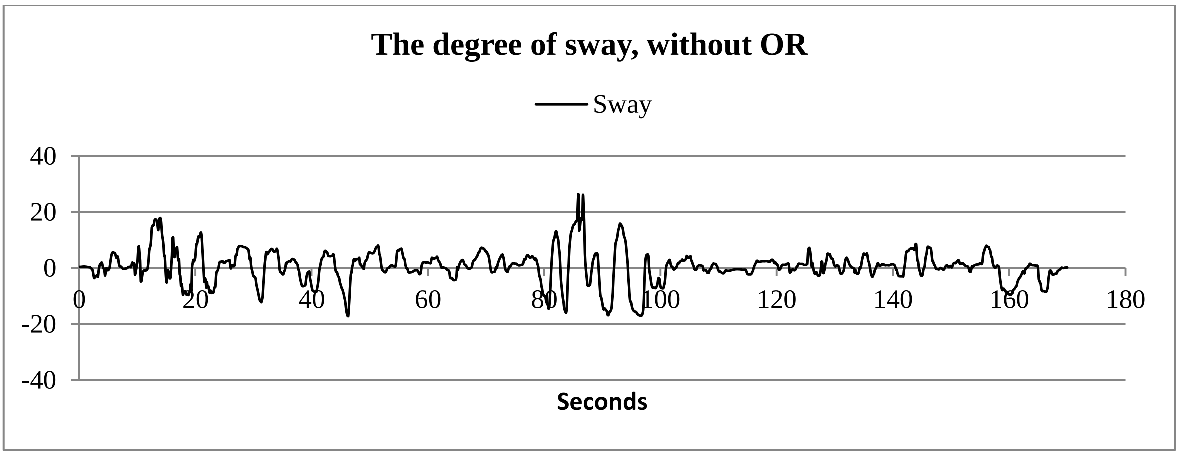

Figure 7. *E.T. performing the game without OR.*

From the semi-structured interview, seven out of eight participants confirmed that it is harder to play the game with the OR; while one said that there is no noticeable difference. Furthermore, six participants stated that, in a matter of balance, it is not safe to use the OR and they felt they lost control over their body. When the participants were asked if they felt any kind of dizziness or nausea while playing the game with the OR, five of them expressed they could not feel anything, while three were mildly affected by motion sickness.

5.4 Study of People with Impaired Balance

The results from the rehabilitation centre at *Sydvestjysk Sygehus, Esbjerg* indicated that five out of six participants experienced higher degree of sway while playing the game with the OR. The video recordings back up the data from the balance board and *Microsoft Kinect*, as it displays participants' difficulties maintaining balance when using OR. This is included in the next section discussions.

6. DISCUSSION

In this section multiple assumptions are presented based on the analysis and the results obtained. The different phases of the study, its limitations and contribution to the field are discussed.

Results from the different phases of the test revealed that full vision is essential in maintaining postural stability, as the majority of participants were affected by losing it. The feasibility test showed that the balance was significantly affected when performing tasks blindfolded. Concerning the graphs, the lines tend to be more fluctuated when the participants executed the tasks blindfolded. The explanation is that loss of vision by closing the eyes usually results in increased sway (Wing, Johannsen and Endo, 2011). The results from the full system test indicated that the adults felt more confident about playing the game on the monitor display. The line is more fluctuated while the control group was playing the game with the OR. The balance-impaired adults presented the same tendency to lose balance when exposed to a VE. It is clear that using OR affects balance negatively, and as Horlings et al, (2009) stated, if the peripheral vision is diminished, the balance will be affected negatively as discovered in their work. However, it is uncertain which factor influences the balance negatively: the loss of peripheral view induced by the game play or the OR. Even if the participants stated, after playing the game, that the level of difficulty was easy, they still had difficulties maintaining their balance. This may lead to the fact that the distortion of peripheral vision was the main factor influencing balance.

From the data collected, there were some contradictory points from different participants. One of the control group participants presented more postural control while using the OR. The reason can be that the participant's balance is more dependent on the other sensory systems that affect balance, i.e. vestibular and somatosensory (Redfern, Yardley and Bronstein, 2001). Considering the life-style aspects in Table 1, the participants presented different features. Comparing them to the graphs, it cannot be stated how these aspects affected their performance. Two different examples prove this statement. As a first example, R. is a male test participant, 19 years of age, non-smoker, consuming alcohol weekly (approximately 4-10 drinks). He has an active life and sleeps 8 hours per night. Regarding physical exercises, he rated his level of fitness with 6 (above average) and he claimed to exercise 3-4 times per week. On the other hand, the second example is represented by participant M., male, 28 years of age. He is a non-smoker and he consumes alcohol weekly, approximately 4-10 drinks. He has an active life and he sleeps around 7 hours per night. Concerning physical activity he rated his fitness level with

4 (less than average) and he does not exercise at all. Even though these two examples present different lifestyles it cannot be seen in the data if their condition affected their in-game performance.

There are several risks involved when being exposed to a VE. Wenzel, Castillo and Barker (2002) testified in their work that problems such as eyestrain, headache, nausea and dizziness are potential symptoms while or after using a HMD. These symptoms appear as a common effect of the contradiction of sensory systems. This is called motion sickness, as stated by Cobb and Nichols (1998). In this matter, the findings indicated that five out of eight participants did not present any symptoms of motion sickness. Still, three participants were feeling dizzy or nauseated during or after playing the game with the OR.

According to the physiotherapists who supervised the test, the balance-impaired adults should have presented more postural instability due to their age and the poor heart condition. However, the results revealed that there were no significant differences between the groups, when exposed to a VE through the OR. Though, it can be stated that the balance-impaired adults tended to be more afraid of the exposure to VR.

6.1 Limitations of the Study

By the time this study was conducted, the OR was an innovation of the market and there were limited research and related work regarding this HMD. This made it difficult to evaluate the study in the field of rehabilitation through VE. There were also limitations while using *Microsoft Kinect* as a measurement device, because it only recognized a certain kind of body movements (for example, leaning). This led to corrupted data for two of the participants. Furthermore, the questionnaire was insufficient, since the resource is more life-balance related rather than physical balance related.

6.2 Further Development

After the test session from the rehabilitation centre, physiotherapists provided feedback regarding the study. The balance board and *Microsoft Kinect* can be used as sensory devices and the game can be improved. This improvement refers to the physical exercises (concerning the knees and ankles) included in the game.

7. CONCLUSION

The main objective of this study was to investigate if the physical balance of young adults is affected by a VE displayed with the OR. It can be concluded that the participants experienced poorer balance while using the OR. Most of the participants had difficulties maintaining their postural stability in a VE. The only notable difference in balance-impaired adults exposed to a VE compared to the control group was that the former tend to be more insecure while playing the game with the OR. Regarding the lifestyle of the participants, it cannot be concluded how it influences physical balance in connection with a VE. Although, it can be concluded that balance-impaired adults that suffer from poor heart condition reacted similar to the control group, when exposed to a VE. Concerning peripheral vision, it can be concluded that it is a primordial influence for physical balance. All the participants showed a better postural stability when performing the tasks with full vision and they were physically unstable when blindfolded. The same situation occurred when they experienced the game with the OR.

In conclusion, a VE induced through the OR, has a negative impact on physical balance. The difference between postural stability while using the monitor display compared to the OR is noticeable. It was not proved if the characteristics of the OR were the main cause of the instability. Therefore, further research and testing are needed to conclude if different types of HMDs have the same effect. Based on the feedback received from specialists, the setup can be transformed into a rehabilitation device.

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[1]Sydvestjysk Sygehus Esbjerg is a hospital located in Esbjerg, Denmark

Virtual reality system for the enhancement of mobility in patients with chronic back pain

B Bolte[1], M de Lussanet[2], M Lappe[2]

[1,2]Institute of Psychology, [2]Otto Creutzfeldt Center for Cognitive and Behavioral Neuroscience,
University of Münster,
Fliednerstr. 21, 48149 Münster, GERMANY

b.bolte@uni-muenster.de, *lussanet@uni-muenster.de*, *mlappe@uni-muenster.de*

ABSTRACT

Back pain is among the most common health problems in the western world. While surgery can reduce pain and disability for patients with symptoms specific to spinal degeneration, for chronic back pain (CBP) patients exist a variety of therapeutic interventions, which are, unfortunately, not very effective. In addition, CBP patients tend to develop a fear of movement (kinesiophobia) and stiffness of the trunk that probably lead to further problems due to reduced physical activity. To address these problems, we propose a virtual reality system using head-mounted displays for the enhancement of mobility in CBP patients. We manipulate the visual feedback to change the motor behavior of participants by applying gains to alter the weight with which neck, back and hip rotations contribute to the orientation of the virtual camera. Users will not notice the manipulation if the gains are sufficiently small. In an evaluation study we showed that our approach has the potential to increase back movement amplitudes in control and CBP participants. Although we have used a specific task, the big advantage of our method is that any task involving body rotations can be used, thereby providing the opportunity to tailor the task to a patient's specific preference or need.

1. INTRODUCTION

Back pain is among the most common health problems in the western world with a lifetime prevalence of 84% (Balagué et al, 2012), and constitutes a major burden in the public health system. For example, costs associated with back pain in Germany were estimated to be in the range of 49 billion Euros in 2008 representing 2.2% of the German gross domestic product (Wenig et al, 2009). Thus, the burden from back pain is immense both for patients and the society. For patients diagnosed with disc degeneration in the spine, surgery can reduce pain and disability (Phillips et al, 2013) but in many patients the symptoms are not specific to spinal degeneration (Fishbain et al, 2014). These chronic back pain (CBP) patients are treated with a number of therapeutic interventions including education about the problem, the participation in daily physical activities, the use of non-steroidal anti-inflammatory drugs, the short-term use of weak opioids, exercise therapy, and spinal manipulations (Dagenais et al, 2010). Multimodal interventions are usually more efficient than monotherapy (Huge et al, 2006, Jensen et al, 2009, Koes et al, 2006, Raspe, 2012). Unfortunately, these back pain treatments are not very effective (Balagué et al, 2012).

CBP patients tend to develop a fear of movement (kinesiophobia) (Swinkels-Meewisse et al, 2003), which in turn is thought to lead to reduced physical activity and increased risk of re-injury (Roelofs et al, 2007). In addition, changes of the motor system are often found in CBP patients such as stiffness of the trunk, which can be related (Karayannis et al, 2013) or uncorrelated (Lamoth et al, 2006) to fear of movement. It is highly desirable to find methods to counteract the changes of the motor system and increase the motility of the back in patients with CBP. Unfortunately, because of pain and/or kinesiophobia it is often difficult to motivate these patients to move. Virtual Reality (VR) systems can be used to distract from pain and anxiety (Hoffman et al, 2001) and motivate patients to move by engaging them in virtual movement games (Sarig-Bahat et al, 2010).

In the present work we describe a VR system that itself exploits the motor adaptation process to induce enhanced movement of the back without the patient being aware of it. Our approach is based on the fact that VR setups, e.g. using head-mounted displays (HMDs), allow us to change motor behavior of users by decoupling the visual feedback from other sensory feedback during movements. This approach has been used for example in

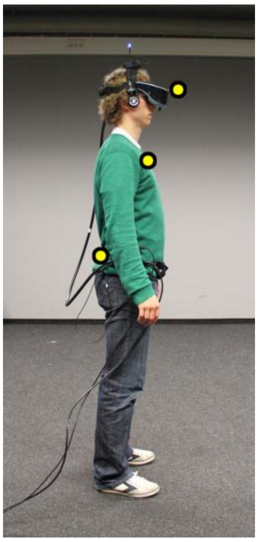


Figure 1. *Illustration of the instrumentation. The participant is wearing the head-mounted display with a fixed infrared marker. Yellow circles indicate the positions of the orientation trackers.*

redirected walking, in which users are led on physical paths that differ from their virtual path (Razzaque, 2005, Bruder et al, 2013), and in the analysis of sensorimotor adaptation of arm movements to perturbed visual feedback of a target (van Beers, 2009, van den Dobbelsteen et al, 2003). For redirected walking, curvature gains are applied, i.e. the virtual camera is slightly rotated and translated with every step of the participant, so that participants physically walk on a curved trajectory while virtually walking straight. If the gain is small enough, users will neither notice the manipulation of the visual feedback nor the adaptation of their motor behavior. Sensitivity to gain manipulations can be investigated using psychophysical experiments to determine gain thresholds for unnoticeable manipulation (Steinicke et al, 2010).

Our goal was to transfer the concept of gain-based visual feedback modification to induce enhanced back rotation amplitudes in CBP patients. We applied gains to change the weight with which neck, back and hip rotations contribute to the orientation of the virtual camera. By changing the weight of the individual rotations, we expected that patients should compensate by also changing the amount of individual rotations. Specifically, by penalizing neck and hip rotations, we expected patients to perform proportionally more back rotations. As this method does not require a particular task in the VE but instead changes the motor behavior by altering the visual feedback during natural movements, it is very versatile. Participants can thus move freely without fixation of any body parts, and patients do not have to be aware that they are actually training.

In order to evaluate the change of motor behavior due to the visual gain manipulation, we designed an experiment in which participants have to move a ring using body rotations (without moving their feet) to catch a flying basketball. We compared the involved proportion of back rotations between a control and a CBP group for two conditions: (1) without gains and (2) with gains to penalize neck and hip rotations.

2. VISUAL-GAIN-BASED CHANGE OF MOTOR BEHAVIOR

In order to render the virtual scene for visual feedback presentation on the HMD, the position and orientation of the virtual camera must be determined. Often, the position and orientation of the head is mapped directly to the virtual camera. We instead want to calculate the head orientation hierarchically based on the orientation of the feet and joints to which we are then able to apply gains.

The yaw orientation with respect to the negative gravity vector (i.e. the orientation in the transverse plane) and relative to a calibrated zero point was determined for the head $\alpha_h \in \mathbb{R}$, upper trunk $\alpha_u \in \mathbb{R}$ and hip (or coxa) $\alpha_c \in \mathbb{R}$ in world coordinate space. Figure 1 shows the placement of the head, upper trunk and hip orientation sensors used for the evaluation of the method.

Based on these orientations the relative rotation of the legs $\theta_h \in \mathbb{R}$ is the orientation of the hip with respect to the world coordinate space, the rotation of the back $\theta_b \in \mathbb{R}$ is the orientation of the upper trunk with respect to the orientation of the hip, and the rotation of the neck $\theta_n \in \mathbb{R}$ is the orientation of the head with respect to the orientation of the upper trunk:

$$\theta_h = \alpha_c, \;\; \theta_b = \alpha_u - \alpha_c, \;\;\; \theta_n = \alpha_h - \alpha_u \tag{1}$$

To determine the yaw orientation of the virtual camera, all rotations were multiplied with gains $g_h, g_b, g_n \in \mathbb{R}$ to introduce a discrepancy between the contribution of hip, back and neck rotations to the orientation of the virtual camera compared to the real world. We calculated the yaw orientation of the virtual camera hierarchically based on the hip, back and neck orientation as follows:

$$\alpha = \; g_h\theta_h + g_b\theta_b + g_n\theta_n \in \mathbb{R}, \tag{2}$$

which is equal to the head yaw orientation if the gains g_h, g_b, g_n are set to 1:

$$\alpha = \; \theta_h + \theta_b + \theta_n = \; \alpha_c + (\alpha_u - \alpha_c) + (\alpha_h - \alpha_u) = \alpha_h \tag{3}$$

The remaining pitch $\beta \in \mathbb{R}$ and roll $\gamma \in \mathbb{R}$ Euler rotation angles were set to the corresponding angles of the head orientation tracker.

Gains below 1 introduce a penalty and gains above 1 introduce an advantage to the individual rotations. For instance, if we choose a gain of $g_n = 0.5$ to penalize neck rotations while not modifying the other rotations ($g_h = g_b = 1$), only half of the rotation amplitude contributes to the yaw orientation of the virtual camera. Assuming that participants would use 45 degrees of neck rotation for a neck gain of $g_n = 1$ to achieve a final yaw orientation, only 22.5 degrees contribute to the virtual camera if the neck rotation is penalized by $g_n = 0.5$. Participants can either compensate the missing 22.5 degrees by performing an additional 45 degrees neck rotation, by using 22.5 degrees of additional back or hip rotations, or any combination thereof. We expected that participants would compensate with more additional rotations of the not penalized rotations compared to the penalized rotations to keep the amount of compensational rotations low. But for participants with CBP the magnitude of compensational back rotations might be severely reduced compared to the participants without CBP, which we evaluated in the following study of motor adaptation caused by our gain-based change of the visual feedback.

3. EVALUATION OF MOTOR ADAPTATION

3.1 Participants

We had a *chronic back pain group* (PG) consisting of 17 participants (6 males, 11 females, age: 16–63, *M* = 42.1, *SD* = 14.8), which had CBP for at least 6 months but were able to stand and walk on their own. The pain was mostly localized in the lower back region. Participants had an average body mass index (BMI) of *M* = 23.65 (*SD* = 3.18). Fifteen participants of the chronic back pain group previously participated in studies concerning CBP, but not involving movement studies in VR.

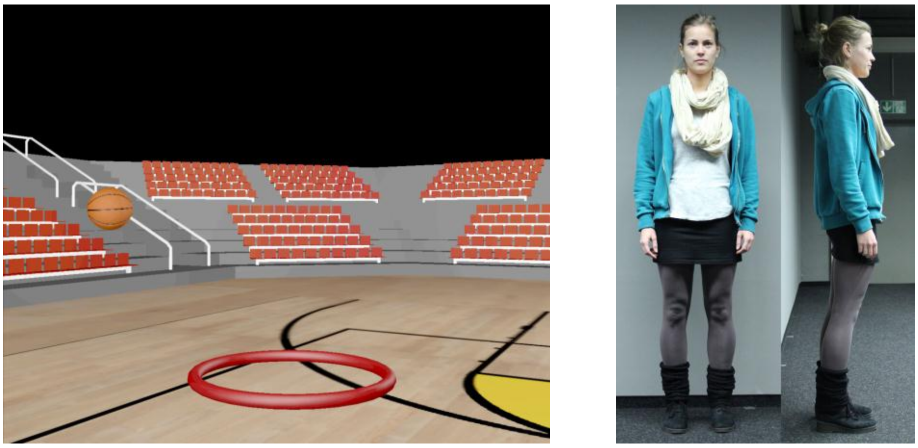
Our *control group* (CG) consisted of 18 participants (5 males, 13 females, age: 20–30, *M* = 23.4, *SD* = 2.5), which had no CBP history. Participants had an average BMI of *M* = 22.06 (*SD* = 1.54). Sixteen participants of the control group were students (mainly Psychology). We discarded the data of one participant as the data set indicated that the participant always rotated the back in the opposite direction of the target, which might be caused by an improper attachment of the orientation trackers.

All participants had normal or corrected to normal vision and were naïve to the experimental manipulation of the visual feedback. Prior to the beginning of participant data collection, the experiment was approved by the local ethical committee.

3.2 Instrumentation

Three InertiaCube 3 orientation trackers from InterSense ($\leq 1^\circ$ accuracy, 4ms latency, 180Hz update rate) determined the orientation of the hip, upper trunk and head in world coordinate space (see Figure 1). The tracker for the head orientation was attached to an extension board mounted on the displays of the HMD. The tracker for the upper trunk orientation was placed with medical tape on the skin at the sternal notch. The tracker for the hip orientation was placed with medical tape on the skin at the superior end of the sacral crest. We put a fresh cotton pad between tracker and skin for each participant. To increase the accuracy of the orientation tracker, we disabled all data filtering, which also slightly increased data jittering.

An active infrared marker was attached to the head-mounted display (see Figure 1). The Precision Position Tracking (PPT) X4 system from WorldViz (< 1mm precision, < 1cm accuracy, < 20ms latency, 60Hz update rate) tracked the marker to determine the participant's position in world coordinate space.



(a) *(b)*

Figure 2. *Illustration of (a) the virtual basketball arena and (b) the calibration pose.*

We used a computer with 3.4GHz Intel Core i7 processor (16GB main memory) and Nvidia GeForce GTX 680 graphics card in surround screen mode for three displays with a total resolution of 3840×1024 pixels. The virtual scene was stereoscopically rendered using the Ogre3D rendering engine (http://www.ogre3d.org/) and our own software. We displayed the rendered images on the Sensics zSight head-mounted display (60° vertical field of view, 2560×1024 pixels resolution, 60Hz update rate). The refresh rate for rendering was synchronized with the refresh rate of the displays. On the third display we rendered the view of both eyes and additional debug information to monitor the progress of the experiment.

3.3 Virtual Environment

The virtual environment consisted of a virtual basketball arena with a width of 20 meters, a depth of 40 meters, and a height of 7 meters (see Figure 2(a)). Participants were located in the center of the basketball arena. The red ring was positioned 0.35 meters below the eye level and 1.5 meters directly in front of the participant, i.e. the ring rotated on a circle with 1.5 meters radius around the participant and the rotation angle was equal to the rotation angle of the virtual camera. The radius of the ball was 0.12 meters and 0.2 meters for the ring.

We simulated the ballistic trajectory of a basketball during passing with a constant speed towards the participant of $s = 8.33$ meters per second (approximately 30km/h), but adjusted the duration of the ball flight to $\Delta_t = 3$ seconds so that participants had enough time to comfortably catch the basketball with the ring. The start position of the basketball was determined on a circle with radius 6.5 meters around the participant with a distance of $\Delta_z = 5$ meters from the ring. The ball start and end position was 0.35 meters below the eye level of participants, i. e. a height offset of $\Delta_y = 0$ meters. We simulated the trajectory assuming gravity $g = 9.31$ meters per square second in a physical vacuum. Without loss of generality, we can calculate the trajectory in the *yz*-plane in model coordinate space, where the y-axis represents the height offset and the z-axis represents the distance between basketball and ring. Arbitrary ballistic trajectories for a given target angle and height above the floor were achieved using an appropriate transformation of the ball position from model to world coordinate space. Thus, the position of the basketball $p(t) \in \mathbb{R}^3$ at a certain point in time $t \in \mathbb{R}$ is given by $p(t) = \frac{(\lambda t)^2}{2} a + \lambda t v + p_0$ with the basketball start position $p_0 = (0, 0, \Delta_z)^*$, constant velocity $v = (0, g\Delta_z/2s, -s)^*$, constant acceleration $a = (0, -g, 0)^*$ and time scaling factor $\lambda = \Delta_z/s\Delta_t$, where the star notation $(\cdot)^*$ denotes the transposed vector.

3.4 Procedure

We welcomed the participants and gave a short introduction to the experimental procedure. Afterwards, we obtained written consent and participants filled out pre-questionnaires.

We measured the eye level of the participants and individual interpupillary distance for the stereoscopical rendering. Afterwards, we attached the orientation trackers on the participants and participants put on the HMD. The laboratory room was completely darkened during the experiment. Participants received on-screen instruction about the task in a slide show.

To calibrate the system, participants stood straight and still to assume a calibration pose as illustrated in Figure 2(b). While participants were in the calibration pose, the experimenter set the yaw orientation of all orientation trackers to 0 degrees and set the current head position as reference to calculate the relative movement for the rendering.

Participants performed a dynamic virtual basketball catching task within a basketball arena in which they had to align a virtual ring with the trajectory of a flying basketball to catch the ball. To localize the ball and align the ring, participants had 3 seconds. Participants used only body rotations to move the ring and were instructed that they must not move their feet. At the end of each trial, participants received feedback about their success or failure using a text overlay for 2 seconds. Then, the next trial started.

The experiment was divided into a training block and two experimental blocks: (1) baseline block without visual feedback manipulation ($\mathrm{g}_h = \mathrm{g}_b = \mathrm{g}_n = 1$), (2) test block with visual feedback manipulation ($\mathrm{g}_h = \mathrm{g}_n = 0.5, \mathrm{g}_b = 1$) in which the neck and hip rotations were penalized. The gains for the visual feedback manipulation were based on results of preliminary testing. Each experimental block consisted of 100 trials with basketballs coming from a 45 degrees angle alternately from the left and the right. Between the experimental blocks was a short break in which a video was shown on the HMD to mask the transition between the blocks.

The training block consisted of 10 trials in which the basketball was coming from 0 degrees to 90 degrees alternately form the left and the right. In each training trial the angle of the basketball was increased by 10 degrees. We checked the 90 degrees angle to ensure that participants were able to perform the second block of the experiment in which larger rotations were required to compensate for the neck and hip rotation penalty.

At the end, the experimenter took off all devices. Then, participants filled out post-questionnaires, were informally interviewed and debriefed. The total time per participant including instructions, training, experiment, breaks, questionnaires and debriefing took 60 minutes while the actual experiment took approximately 12 minutes.

3.5 Recorded Measures

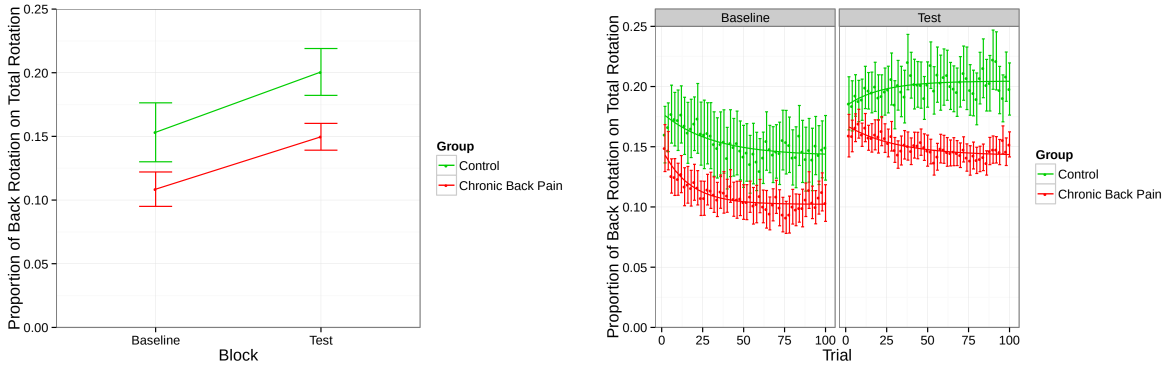
We recorded the tracked position and orientation data with a sampling rate of 60Hz. In particular, we recorded the hip, back and neck orientation at the end of each trial for further analysis. Additionally, we noted whether the ball was successfully caught during the trial.

Participants filled out the German version of the Tampa Scale of Kinesiophobia (TSK-DE) to investigate their pain related fear of movement/(re)injury (Kori et al, 1990, Vlaeyen et al, 1995, Nigbur et al, 2009). As the evaluation experiment involves relatively fast rotational movements and the visual feedback differed from the real movement in the test block, we wanted to record the level of simulator sickness caused by the experiment. Therefore, participants filled out Kennedy's simulator sickness questionnaire (SSQ) immediately before and after the experiment (Kennedy et al, 1993). In addition, participants filled out the Slater-Usoh-Steed (SUS) presence questionnaire (Usoh et al, 1999), and a questionnaire collecting anthropologic data and informal responses after the experiment.

3.6 Data Analysis

For statistical analysis, we used the R software (version 3.0.2) from R Foundation for Statistical Computing (R Core Team, 2013). Significance was determined at the level of $p \leq 0.05$ for all comparisons. We tested the assumption that the data is normally distributed with the Shapiro-Wilk test. The age of the participants and the TSK-DE scores were compared between groups using the Welch two sample t-test, and the pre and post SSQ scores were tested for significant differences using the paired t-test. All questionnaires were additionally analyzed using non-parametric tests (Wilcoxon Rank Sum and Signed Rank Tests).

For the analysis of changes in motor behavior concerning back rotations of participants induced by our approach, we calculated the proportion of the back rotation on the total body rotation $p_b = \theta_b/(\theta_h + \theta_b + \theta_n)$, where $\theta_h, \theta_b, \theta_n$ are the hip, back and neck rotations at the end of the trial. As penalizing some of the body rotations of participants inevitably lead to an increase of the amount of body rotations including the back rotation of participants, we analyzed the proportion of the back rotation on the total body rotation. The repeated measures of each experimental block were averaged to provide one proportion of back movement for each block and each participant. All trials in which the basketball was not caught, i.e. the participant had not performed the intended rotation, were discarded (67 of 6800 trials, < 1%). We used Levene's Test to analyze variance homogeneity between the groups. In a 2 (group: CG, PG) × 2 (block: baseline, test) mixed model analysis of variance (ANOVA) we tested for differences between groups and between experimental blocks. For significant effects, we performed post-hoc pairwise comparisons using paired and Welch two sample t-tests.



(a) *(b)*

Figure 3. *Result plots for the proportion of back rotations on the total body rotation at the end of each trial. The error bars indicate ±1 standard error of the mean. (a) Mean proportion of back rotation for both groups and both experimental blocks. Chronic back pain participants use on average less back rotation compared to the control participants. The proportion of back rotations was increased during the test block for both groups. (b) Time course of the proportion of back rotation for both groups and both experimental blocks. The solid lines show the fitted exponential functions* $(a-b)e^{-t/\tau}+b$*. While the motor adaptation of participants is similar for both groups in the baseline block, it differs during the test block. Control group participants increased their proportion of back rotation over time until an asymptotic limit was reached in the test block. Otherwise, participants decreased their proportion of back rotation over time.*

In addition, we investigated the time course of motor behavior adaptation induced by our approach in order to measure the stability of the effect over time. Therefore, we fitted the exponential function $(a-b)e^{-t/\tau}+b$ to the proportion of back rotation using a non-linear least squares fit. The time constant $\tau \in \mathbb{R}$ reflects the speed of adaptation from an initial towards an asymptotic proportion of back rotations $b \in \mathbb{R}$, the time in trials is denoted by $t \in \mathbb{R}$, and $a \in \mathbb{R}$ is the intercept at time $t = 0$. We combined the rotation directions for each participant by averaging every two consecutive trials, as the basketball came alternately from the left and right side. Then, the proportion of back rotation was averaged over all participants for each trial.

3.7 Results

Figure 3(a) shows a comparison of the mean proportion of back rotation on the total body rotation of participants between the baseline block (without visual feedback manipulation) and the test block (with visual feedback manipulation) for both groups. Participants of the control group showed a significantly higher variability of the proportion of back rotation compared to the participants with CBP in the test block, $F(1,32) = 4.24$, $p < 0.05$, and a trend for higher variability in the baseline block, $F(1,32) = 3.91$, $p = 0.057$. There was no interaction effect between the factors group and block, $F(1,32) = 0.11$, $p = 0.74$. We found that both the group, $F(1,32) = 4.63$, $p < 0.05$, and the block, $F(1,32) = 21.52$, $p < 0.001$ had a significant effect on the proportion of back rotation. Post-hoc analysis revealed that the average proportion of back rotations was greater in the test block (CG: $M = 0.20$, $SE = 0.02$, PG: $M = 0.15$, $SE = 0.01$) compared to the baseline block (CG: $M = 0.15$, $SE = 0.02$, PG: $M = 0.11$, $SE = 0.01$) for both the control group, $t(16) = -2.93$, $p < 0.01$, $r = 0.59$, and the CBP group, $t(16) = -4.07$, $p < 0.001$, $r = 0.71$. In addition, the average proportion of back rotations was significantly greater for the control group ($M = 0.20$, $SE = 0.02$) compared to the CBP group ($M = 0.15$, $SE = 0.01$) in the test block, $t(25.45) = 2.40$, $p < 0.05$, $r = 0.43$, but differed not significantly between the groups (CG: $M = 0.15$, $SE = 0.02$, PG: $M = 0.11$, $SE = 0.01$) in the baseline block, $t(25.76) = 1.66$, $p = 0.11$, $r = 0.31$. As the age of participants differed significantly between the control and CBP group, $t(16.92) = -5.09$, $p < 0.001$, $r = 0.78$, we compared the control group to a subset of the CBP group with an age range similar to the control group (3 males, 3 females, age: 16–31, $M = 24.2$, $SD = 6.4$) to investigate whether the group difference was mainly driven by age. These comparisons also revealed that the average proportion of back rotations was significantly greater for the control group ($M = 0.20$, $SE = 0.02$) compared to the subset of the CBP group ($M = 0.15$, $SE = 0.01$) in the test block, $t(20.87) = 2.34$, $p < 0.05$, $r = 0.46$, but differed not significantly between the control group ($M = 0.15$, $SE = 0.02$) and the subset of the CBP group ($M = 0.12$, $SE = 0.02$) in the baseline block, $t(18.60) = 1.05$, $p = 0.31$, $r = 0.24$.

Figure 3(b) shows the time course of the mean proportion of back rotation on the total body rotation for both groups and both experimental blocks. The solid lines show the fitted exponential functions $(a-b)e^{-t/\tau}+b$ for each combination of group and experimental block. In the baseline block, the motor adaptation of participants

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seemed to be similar for both groups. The average proportion of back rotation decreased over time (time constants: CG τ = 30.4072, PG: τ = 16.4344) from an initial proportion of back rotations (intercepts: CG: a = 0.1783, PG: a = 0.1487) towards the asymptotic limit (CG: b = 0.1425, PG: b = 0.1022). In contrast to the baseline block, the motor adaptation of participants differed between the groups in the test block. For the control group, the average proportion of back rotations increased over time (time constant: τ = 21.4383, intercept: a = 0.1837) towards the asymptotic limit (b = 0.2046), but decreased over time (time constant: τ = 30.9652, intercept: a = 0.1682) towards the asymptote (b = 0.1425) for the CBP group. The difference between intercept and asymptote was similar between the groups (CG: 0.0209, PG: 0.0257) in the test block and decreased in the CBP group from the baseline block (0.0465) to the test block (0.0257) by 44.7%. In the CBP group the time constant increased from the baseline block (τ = 16.4344) to the test block (τ = 30.9652) by 88.4%.

We found no difference for pain related fear of movement using the TSK-DE questionnaires between the control group (CG) (M = 28.20, SE = 1.37) and the chronic back pain group (PG) (M = 32.38, SE = 1.93), $t(26.71) = -1.76$, $p = 0.09$, $r = .32$ (3 participants were excluded due to missing answers in the questionnaire). The simulator sickness caused by the experiment differed between the groups. In the CBP group, there was no significant difference between the mean SSQ score before the experiment (M = 29.7, SE = 6.90) and after the experiment (M = 36.3, SE = 8.05), $t(16) = -1.11$, $p = 0.28$, $r = 0.27$, whereas the SSQ score significantly increased from M = 8.14, SE = 1.58 before the experiment to M = 30.8, SE = 9.03 after the experiment for the control group, $t(16) = -2.81$, $p < 0.05$, $r = 0.58$. Participants rated their sense of presence in the virtual basketball game with an average score of M = 3.60, SE = 0.27. We found that on average participants of the control group rated their sense of presence (M = 4.16, SE = 0.36) significantly greater than the participants of the CBP group (M = 3.05, SE = 0.36), $t(32.00) = 2.18$, $p < 0.05$, $r = 0.36$.

4. DISCUSSION

The results of our evaluation show that our approach to manipulate the visual feedback using gains to penalize specific components of the body rotations is a viable way to change the motor behavior. Participants of the control group made proportionally more back rotations and showed a higher variability of back rotations compared to the CBP patients. We expected this difference between the control and CBP participants due to the often-found stiffness of the trunk in CBP patients as stated in the introduction. Although the control participants were considerably younger than the CBP patients, we found no evidence that the difference in back rotations between groups was mainly driven by the age of participants. It is interesting to note that in the test block the CBP group showed nearly the same average proportion of back rotations compared to the control group in the baseline block, which suggests that CBP participants used less back rotations in the baseline block even though they were generally able to use the same amount compared to control participants. More importantly, despite the differences between the groups, both groups increased the back rotation in the test block by an equal amount compared to the baseline block and therefore showed the same response to the visual feedback manipulation. On average participants proportion of back rotations on the total body rotation was increased by 4.7% for the control group and 4.1% for the CBP group to accomplish the goal of catching the ball, when the hip and neck rotations were penalized with a gain of 0.5.

For the motor adaptation over time, we expected that participants learn the benefit of back rotations compared to the other rotations in the test block. Indeed, we found that the control group increased the proportion of back rotations during the test block. The CBP group slightly decreased the proportion of back rotations, but less and slower than in the baseline condition. A likely interpretation is that CBP patients chose a strategy in-between the benefit of using more back rotations compared to the other rotations and the CBP-typical minimization of back movements.

The CBP group was not kinesiophob according to a cut-off score of 37 (Vlaeyen et al, 1995). This shows that our sample of CBP patients represents a different selection from the population than in typical studies for validating kinesiophobic measures. However, the mean TSK score for the CBP group was comparable to symptomatic groups of other pain related movement studies in virtual reality environments (Sarig-Bahat et al, 2010). Since the CBP patients made less back rotations our study supports the results by Lamoth et al. (2006) who found that the kinematic changes during walking were not correlated with fear avoidance measures.

Some participants had problems with the VR hardware and reported that the HMD pressed on the forehead after time. However, in the CBP group no simulator sickness was caused by the visual feedback manipulation of the experiment. Although we found that in the control group simulator sickness was increased after the experiment, the effect was mainly driven by three participants with a large deviation of the pre- and post-SSQ score difference to the other participants of the group. This was also manifested in a non-normal and skewed distribution of the data, which is problematic for the statistical tests. The difference between pre- and post-SSQ score is comparable to findings of visual feedback manipulation in redirected walking experiments (Steinicke et al, 2010). Therefore, we assume that some participants are vulnerable to simulator sickness in general and the experiment did not caused unexceptional simulator sickness.

While the evaluation has shown the potential of the approach to alter the motor behavior of participants, in a next step the clinical applicability of the approach must be tested. In particular, it would be of interest to investigate if CBP patients also use more back movements in real life after taking part in the virtual reality session. Another interesting question is if training during repeated usage of the approach reduces the pain intensity and thus improves the quality of life of these patients. One may also expect that patients are more willing to use playfully virtual training compared to plainly performing the involved movement exercises, but this remains to be tested. Although we have used a specific task (ball catching) to evaluate our system, one must keep in mind that the big advantage of our method is that no particular task is required to induce the increase of back rotations. Instead any task involving body rotations can be used, thereby providing the opportunity to tailor the task to a patient's specific preference or need. Likewise, although our system is developed for patients with problems of the lower back, similar approaches could be used for other movements and problems, such as neck or shoulder pain.

Acknowledgements: Authors of this work are supported by the Deutsche Forschungsgemeinschaft (DFG 29160962) and Bundesministerium für Bildung und Forschung (BMBF 01EC1003A). We thank Lina Valtin and Sascha Kuck for their help with conducting the experiment.

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The application of enhanced virtual environments for co-located childhood movement disorder rehabilitation

N H Mumford[1], J Duckworth[2], P H Wilson[1]

[1]School of Psychology, Australian Catholic University,
Melbourne, AUSTRALIA

[2]School of Media and Communication, RMIT University,
Melbourne, AUSTRALIA

nhmumford@gmail.com, peterh.wilson@acu.edu.au, jonathan.duckworth@rmit.edu.au

[1] *www.acu.edu.au,* [2] *www.rmit.edu.au*

ABSTRACT

In this paper we discuss potential benefits and future directions in virtual reality rehabilitation for co-located motor training in children with developmental movement disorders. We discuss the potential for co-located VR to promote participation using cooperative virtual environments, facilitate social learning, and quantify levels of social interaction. We pay particular attention to the capacity of co-located systems to enhance levels of participation and the psychosocial outcomes of VR therapy. Finally, we offer directions for future research.

1. INTRODUCTION

Developmental movement disorders (DMD) like Cerbral Palsy (CP) and Developmental Coordination Disorder (DCD) effect approximately 0.2% (Oskoui, Coutinho, Dykeman, Jetté and Pringsheim, 2013) and 5-10% (Henderson and Henderson, 2002) of children, respectively, and are characterised by significant disruption to functional capabilities. CP is diagnosed when neurological damage has occurred prenatally or during birth, and typically results in more severe movement deficits (Liptak and Accardo, 2004). Conversely, DCD is described in the DSM-V (APA, 2013) as ‘clumsiness’ in children, and is not associated with overt neurological damage (see (Wilson, Ruddock, Smits-Engelsman, Polatajko and Blank, 2013) for review). Though diagnostically distinct, CP and DCD are both characterised by varying degrees of motor coordination deficit in upper- and lower-limb function, and postural control (Spittle and Orton, 2013). Recent theory suggests that DMDs may share similar neuro-cognitive deficits associated with higher order motor control and executive processes, causing disordered movement (Pearsall-Jones, Piek and Levy, 2010). For example, working memory dysfunction, especially in task situations that are time-limited, is seen as a common deficit among DMD children (Jenks et al., 2007; Piek, Dyck, Francis and Conwell, 2007). Moreover, it is well documented that the movement problems associated with DMDs commonly result in long-term psychosocial deficits (Bottcher, 2010; Chen and Cohn, 2003). These may include isolation, low self-esteem, reduced social support, and elevated anxiety (see (Bottcher, 2010; Chen and Cohn, 2003) for review). Sobering is the fact that psychosocial problems of this type in childhood are associated with later psychopathology in adulthood (Kessler et al., 2010).

The presence of psychosocial deficits associated with DMDs highlights a need for social interaction to be included as a core part of rehabilitation, enabling higher rates of participation, more opportunity for skill development and acquisition of social competencies. For example the Breathe Magic program, founded in the UK, requires groups of children with hemiplegia to learn (bi-manual) magic tricks, such as card tricks, culminating in a magic show after the 3-week program (Green et al., 2013). This program has demonstrated significant improvements in motor function (Green et al., 2013) and, based on child and parent reports, improved engagement with typically-developed peers and family members at home. Other group-based movement rehabilitation programs have found similar results (Aarts, Jongerius, Geerdink, Limbeek and Geurts, 2010; Dunford, 2011; Hung and Pang, 2010; Pless, Carlsson, Sundelin and Persson, 2000).

We are unaware of any research with the dual aims of improving psychosocial outcomes among DMD populations in addition to movement skill. Any such study would still need to address issues that are part and parcel of any rehabilitation program. Notable among these are that rehabilitation requires significant time and resources to organise and that repetition in therapy can be experienced as boring, sapping motivation, particularly in children (Wang and Reid, 2011). The application of new technologies needs to be mindful of these issues if the efficiency and efficacy of treatments are to be enhanced. Virtual Reality (VR) technologies are widely thought to offer a number of exciting options for augmenting current rehabilitation practices (Rizzo, Schultheis, Kerns and Mateer, 2004). Yet little work has addressed the use of VR systems to encourage co-located interaction, providing a dual lever for movement and social skill development in children with DMD. In this paper we provide a conceptual and empirical rationale for VR-rehabilitation of DMDs, detailing the dual advantages of co-located systems for movement and social skill development specifically in this broad population. We then describe applications of co-located VR in paediatric rehabilitation, and make design proposals for the future.

2. ADVANTAGES OF VIRTUAL REALITY REHABILITATION AMONG CHILDREN WITH MOVEMENT DISORDERS

VR and associated technology is a combination of computer/information technology that allows users to interact efficiently with simulated programs in real-time. VR promotes a sense of participation within the virtual environments (VEs) and allows clinicians to present relevant stimuli that are embedded in a meaningful and recognisable context (Riva, 2002). Some key advantages to VR-rehabilitation are: greater enjoyment and engagement with rehabilitation; greater control and adaptability of tasks, provision of augmented feedback, and automated data collection (Burdea, 2003; Thornton et al., 2005). Accordingly, research has explored these advantages among child populations. For instance, our prior project, Elements, which was developed for adults with traumatic brain injury (Duckworth and Wilson, 2010), was adapted for children with hemiplegia. The adapted rehabilitation system called RE-ACTION utilised a horizontal table-top display requiring children to move soft graspable objects (e.g. a cylinder 60mm diameter, 90mm height) to prompted positions on the screen. During these movements the VE provided real-time augmented feedback to the children, and tracked performance variables (e.g. movement speed) (Green and Wilson, 2012). After three weeks of therapy, the children demonstrated significant improvements in motor control, based on system-measured and standardised assessments. They also reported finding the VR-tasks more enjoyable than their usual rehabilitation (Green and Wilson, 2012). Following on from such positive results, it is plausible that VR programs encouraging multiple users to interact (i.e. co-located VR) may offer specific advantages for enhancing motor-control, and psychosocial outcomes in DMD populations.

2.1 Advantages of co-located VR-rehabilitation

2.1.1 Cooperative VEs promote participation. Perhaps the primary advantage in using co-located VR among DMD populations is the potential to design and customise the programs to promote participation. Based on the International Classification of Functioning, Disability, and Health – Children and Youth Version (ICF-CY), the standard for conceptualising levels of function and planning rehabilitation, participation refers to a child's involvement in physical, recreational, and social life situations (WHO, 2007). Critically, participation covers more than merely being physically able to take part in life situations, but includes a sense of belonging, and of being involved in these social settings (Granlund, 2013). This highlights the need to develop social skills as part of a rehabilitation framework/system that has as its primary aim, motor function. As shown in Figure 1, the ICF-CY model proposes a bi-directional relationship between reduced participation and negative personal outcomes (see (Granlund, 2013; Rosenbaum and Stewart, 2004) for further discussion on participation).

We contend that using engaging VEs that promote physical movement training, together with social interaction, may improve the physical, social, and recreational aspects at the participation level in the ICF-CY model (WHO, 2007), and reduce both motor and psychosocial deficits in DMD children, while leveraging their interest and motivation. For instance, the successful completion of VR tasks involving collaboration may improve psychosocial function, enhancing self-esteem, and confidence. The ability to match task levels and challenges to capabilities may also promote a sense of competency, further improving participation. As an illustrative example, in a VR-rehabilitation program called the VRSS system, which has been successfully used to improve upper-limb movement among children with hemiplegia, participants wear movement sensors on their hand, and back (to track posture), and perform tasks projected on a vertical display. One such task is to pick up coloured cubes, and stack them (Olivieri et al., 2013). This program could, potentially, be expanded to include multiple users, and encourage cooperative interaction. For instance, two users could coordinate in the block lifting and stacking exercise, with one manipulating red blocks into the stack, while another moves blue blocks.

2.1.2 Potential for social learning. Social/observational learning is a critical aspect of child development (Pratt et al., 2010). Co-located VR programs can provide opportunities for children to observe how their peers perform tasks in the VE, and develop new movement strategies of their own. Peer modelling has been shown to be pivotal in learning fundamental motor skills in both typically developing and less skilled children (O'Connor, Alfrey and Payne, 2011). Another possibility is allowing children already familiar with the VR programs to 'mentor' new participants, teaching them how to interact with the VEs. This may provide opportunities for social learning for the new participant, and 'teaching' may be a positive experience for the more experienced child.

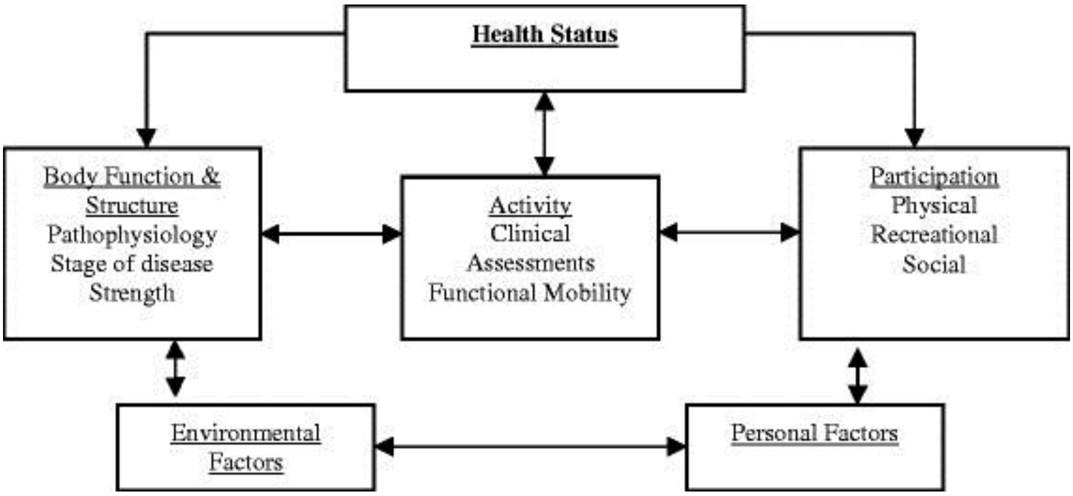

Figure 1. *The ICF-CY model of functioning and disability (WHO, 2007).*

2.1.3 Automatic quantification of social interaction. Social interaction can be a difficult construct to quantify (Crowe, Beauchamp, Catroppa and Anderson, 2011). Current methods rely on self-report, or parent-report questionnaires, or structured observation protocols (see (Crowe et al., 2011) for review). Each of these has inherent limitations. For instance, the potential for creating 'social desirability bias' (Cook and Oliver, 2011). Co-located VR programs, however, may allow researchers or clinicians to record aspects of social interaction between users. For instance, a VE requiring users to coordinate to achieve a goal may track speed of task completion, or how closely participants coordinated their movements, over successive trials to gauge user interaction/coordination. Digital markers on the hand/wrist may also be used to track participants' movements in space while using the VE. This would permit assessment of movement patterns in peripersonal and extrapersonal space, field preferences (ipsi- and contralesional), and interactions between users. In addition, aspects of speech, gesture and facial expression could be recorded as metrics of social interaction. For instance, turn taking in speech may be a useful metric for children with DMD and/or Autism Spectrum Disorders.

3. CURRENT APPLICATION OF CO-LOCATED VR-REHABILITATION IN CHILDREN, AND DIRECTIONS FOR FUTURE RESEARCH

In reviewing the VR-rehabilitation literature, examples of co-located VR were confined largely to Autism-spectrum disorders (ASD). However, even in this population where social skill deficits are a defining feature, very few examples of such systems are available. Generally, VEs either require a single user to interact with an avatar (e.g. (Mitchell, Parsons and Leonard, 2007)), or enlist a multi-user set-up but participants interact within the VE from separate locations (e.g. (Cheng, Chiang, Ye and Cheng, 2010)).

3.1 Co-located VR-therapy in Autism-spectrum populations.

To date, the bulk of research on the use of co-located VR for ASD has emanated from the Weiss lab in Israel (Bauminger et al., 2007; Gal et al., 2009; Giusti, Zancanaro, Gal and Weiss, 2011). Their StoryTable program is a table-top system promoting social skills and interaction. Using a large touch-screen interface, pairs of children interact with the VE to tell a fairy-tale. Participants must both coordinate on selecting constructs for the story (i.e., setting, sounds, music, characters and so on) by touching icons on the screen, and then creating the story. Evaluations of this program have been positive, although based largely on observational assessments. The children found the program easy to use, enjoyable, and demonstrated increased levels of social interaction skills (Gal et al., 2009). Another such system is the SIDES program (Piper, O'Brien, Morris and Winograd, 2006). This table-top VR-system requires four children to solve a movement puzzle collaboratively. Here, children work together in order to direct a frog avatar safely through a virtual space (a 7 x 9 tile grid) by placing virtual direction tiles on the screen (e.g. move one space straight ahead). Initial case-study testing showed that children with Asperger's Disorder found the program engaging, and that it facilitated social interaction during the course of the program (Piper et al., 2006). However, no data is yet available to demonstrate transfer to the activities of daily living that require social skills. Nevertheless, the successful application of these co-located VR programs further highlights the potential application among DMD populations.

3.2 Directions for future research

As discussed above, the application of co-located VR in the rehabilitation of DMDs offers distinct advantages (Park et al., 2011). The foremost being the potential to facilitate participation. To further the field we propose that the broad approach to therapeutic design be embedded in current theories of motor learning and psychosocial function (particularly ecological approaches to learning), design elements be presented in a manner that engages and motivates users in a group context, and assessment protocols be developed to evaluate the efficacy of co-located systems at multiple levels of function. Therefore, we propose three key stages that must be considered in the development and experimental testing of future co-located VR rehab systems.

The first stage in the process is to ensure that the design and testing methods are firmly grounded in motor control/learning and developmental principles that underpin our understand of DMDs (Wilson, 2012). At the level of motor control, for example, computational models hold that predictive online control is critical to the flexible and efficient control of movement. Consistent with this view, children with DMDs show difficulties in the ability to enlist predictive control when planning and correcting movements in real time (Pearsall-Jones et al., 2010). These difficulties may be compounded by additional cognitive deficits like reduced executive function (Wilson et al., 2013). Thus, to prevent cognitive overload, co-located VR-systems need to be simple and intuitive in their interface and task design. Provision of multimodal augmented feedback during the course of movement can assist the development of online motor control, and the ability to make predictive estimates of limb position and body posture. In VR, augmented feedback may involve additional visual or auditory stimuli that are correlated with self-motion; examples include the use of coloured trail effects, musical notes (the loudness of which is correlated to spatial position), and visual ripple effects that signal object placement, all of which accentuate and reinforce the outcomes of the participant’s own action.

Of the second stage, our team has identified several key components of group user interaction from the Computer Supported Cooperative Work (CSCW) field of research: physical space, group awareness, territoriality, and interaction simultaneity (Duckworth, Thomas, Shum and Wilson, 2013). We also propose that design elements from video games such as feedback, rewards, challenges, and social play may increase engagement and intrinsic motivation that support multiple co-located players in rehabilitation (Duckworth et al., 2014). For instance, a VE may provide participants with developmentally appropriate rewards/feedback (e.g. point score related to game performance), both at the level of the individual and the group (a combined reward like unlocking a new game level as the group progresses). The investment in achieving individual or group feedback/rewards could be manipulated by judicious game design. Developers must also consider participants’ personal learning preferences in their VR design (García-Vergara, Brown, Park and Howard, 2014; Novak, Nagle and Riener, 2014). For instance, research indicates that children may inherently prefer co-operative or competitive VR-programs, and as such, may benefit more from their preferred system (Novak et al., 2014). This highlights the need for flexibility in style and delivery of VEs, to tailor the experience to suit the individual user.

Important to the third stage is the development of effective research strategies and protocols to measure and test the efficacy of group based rehabilitation. We put forward several mixed-method approaches to assess social function, motor skills, behavioural change and wellbeing. While performance outcomes can be assessed using established quantitative measures (e.g. the McCarron Assessment of Neuromuscular Dysfunction (Waller, Liu and Whitall, 2008) for motor coordination), more complex constructs like social ability and self-efficacy require a combination of quantitative and qualitative methods. In short, a multi-method approach that includes sophisticated multi-level modelling will allow a thorough assessment of efficacy and longer-term outcomes of co-located VR interventions, informing future adoption of these applications.

Development of VR programs requires a multi-disciplinary approach, with input from computer engineers, artistic designers, physical therapists, and other neuro-rehabilitation specialists. The challenge is the principled development of therapy solutions under reasonable timelines and costs, and their implementation not as a ‘replacement’ for traditional therapies (Parsons, Rizzo, Rogers and York, 2009), but as an adjunct. Available data suggests that the pursuit of co-located VR-rehabilitation is worth the investment, despite these challenges.

4. CONCLUSION

DMDs impact the functioning of children at multiple levels, including motor-control, movement skill, and social function, the sum effects of which can persist into later adolescence and adulthood, if untreated. Developing new therapy solutions, treatment strategies, and rehabilitation technologies to address the combined effect of these problems is vital. VR-rehabilitation can leverage rehabilitation by presenting VEs that afford more opportunities for movement training, participation and social learning, while at the same time providing motion analysis that can resolve both individual behaviour and co-actor interaction. Despite these advantages, it remains surprising that so little research has directly assessed the motor and psychosocial outcomes of such systems. With due attention to systems design, informed by current theory, and to a rigorous (multi-level) approach to assessment, the potential of co-located VR rehabilitation should be realised.

Acknowledgements. This work is supported by an Australian Research Council (ARC) Linkage Grant LP110200802, Synapse Grant awarded by the Australia Council for the Arts, and Australian Catholic University Research Funding.

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Towards a mobile exercise application to prevent falls: a participatory design process

M Sandlund[1], H Lindgren[1], P Pohl[1], A Melander-Wikman[2], B Bergvall-Kåreborn[2], L Lundin-Olsson[1]

[1]Umeå University, Umeå, SWEDEN

[2]Luleå University of Technology, Luleå, SWEDEN

marlene.sandlund@umu.se

ABSTRACT

In this cross-disciplinary project senior citizens and researchers participated in the collaborative design and development of a mobile exercise application to prevent falls. The methods Form-IT and Participatory and Appreciative Action and Reflection were applied in a series of workshops, facilitating the creation of new knowledge and a socio-technical platform for an end-user development process. The participation of the older adults was key to understanding the broad range of preferences and motivational aspects. The outcomes emerged into prototypes, which were composed using the ACKTUS platform for end-user development, resulting in a dynamic application, easily adaptable to future needs and studies.

1. INTRODUCTION

Falls represent the most common cause of injury in old age. At least one third of community-dwelling people aged 65+ fall each year, half of them more than once (Campbell et al, 1989), and the incidence increases with advancing age (Stevens et al, 2006). Falls are declared to induce the most costly consequences among older people, and these costs are expected to increase rapidly if the development continues (Davis et al, 2010). Not only the fall-related physical injuries have devastating consequences for older persons, but fear of falling and decreased balance confidence have major implications for quality of life and health, including loss of functional independence and participation in society. Fear of falling is particularly common among older women (Scheffer et al, 2008). Falls are often a result of the existence of multiple risk factors, such as impaired balance, gait, vision, and drug side effects. Therefore, it has been assumed that interventions that address several of these risk factors, i.e. multifactorial falls prevention, will be most effective. However, according to recent systematic reviews, exercise programmes that focus on balance combined with muscle strength in the lower limbs are as effective in reducing both the number of falls and fallers among community-dwelling older people (Gillespie et al, 2012; Sherrington et al, 2008).

The positive effects of exercise in old age to prevent falls are generally not known by older people (Yardley et al, 2006). There is a lack of guidance on how they can counteract or decrease their fall risk by regaining or maintaining balance capacity and physical strength. Furthermore, for those who are offered fall preventive exercises, low adherence has been reported as a major concern (Fortinsky et al, 2004). Even though evidence consistently suggests that balance and strength exercises are effective in reducing falls and fall related injuries, these kind of interventions are still only effective if the older persons at risk actually adhere to the training and continue to exercise. Average adherence rates to group based exercise programmes as low as 50% to 75% are not uncommon (McPhate et al, 2013; Clemson et al, 2012).

Through innovative technology, preventive interventions like balance and strength exercises for the avoidance of falls can be made available to large populations in both rural and urban areas. A number of reasons for introducing these kinds of welfare technology have been mentioned, but the two most important are: 1) to help in the implementation and adaptation of preventive actions to reduce the effects of chronic diseases and age-related complaints (Mörk and Vidje, 2010), and 2) to empower people and enable them to do things themselves, which they would previously needed help with (Melander-Wikman, 2008). In addition, interactive welfare technology does also have the potential to provide meaningful and motivating exercises, if strategically applied.

Building on existing evidence-based knowledge within the field of falls prevention the aim of the project presented in this paper is to develop, evaluate and implement a best practice fall preventive programme in the shape of an application for smartphones and tablets to be used in people's own homes and surroundings. The goal is to implement the programme on a broad base, equally accessible in urban and rural areas, with the long term ambition to provide effective and empowering prevention methods for healthy ageing and the maintenance of body functions, activity and participation throughout the life span. This project consists of two phases: 1) design phase (design and develop the mobile application for falls prevention together with older women and men; 2) evaluation of implementation and effects phase (pilot study, implementation study, randomized controlled trial).

The aim of the present article is to present the methodology used and resulting experiences from the design phase. Section 2 describes the setup and theoretical background, and Section 3 describes how the theoretical and methodological underpinning was applied in the development process.

2. DESIGNING THE DESIGN PROCESS

A cross-disciplinary research group consisting of researchers in physiotherapy, informatics and knowledge engineering, including experts in falls prevention, e-health, and gender research, planned and carried out a series of workshops for community-dwelling older persons. The purpose of the workshops was twofold: 1) to gain knowledge about older women's and men's understanding of fall risk and falls prevention and their views and preferences regarding fall preventive exercises; 2) to together with potential users, design a mobile application that facilitate the creation of individualized balance and strength exercise programmes that inspire adherence. In addition to the workshops, sessions of design and knowledge engineering were conducted. In these sessions the physiotherapists developed testable prototypes based on their professional knowledge and the results from the workshops. The theories and methodologies applied in the project are described in the following section.

2.1 Theoretical Approaches and Methodologies

In order to design an application, with the main purpose to motivate older people to perform fall preventive exercises, it is of paramount importance to gain a thorough understanding of the views and values underpinning the needs of the future end-users, as well as perceived aspects important for the sustainment of motivation. A lack of such understanding may be one factor that explains the limited adoption of many aging-related technologies (Thielke et al, 2012). Therefore Needfinding and Incitement-finding activities in the form of focus group discussions were central in our methodology (Makosky Daley et al, 2010). In addition, the overall research methodological and philosophical principles underpinning this project has been Form-IT (Ståhlbröst and Bergvall-Kåreborn, 2007) and Participatory and Appreciative Action and Reflection (PAAR) (Ghaye et al, 2008)

Form-IT is a human centred methodology aiming to guide and facilitate the development of innovative services based on a holistic understanding of people's needs, behaviour and values. The approach is an iterative and interactive process inspired by three theoretical streams: Soft Systems Thinking, Appreciative Inquiry, and Needfinding. Soft Systems Thinking provides tools for understanding the worldview of involved stakeholders, including potential end-users, in order to understand their interpretations and understandings of different situations. Appreciative Inquiry provides a focus on opportunities by identifying the dreams and visions of the users. Instead of starting by searching for problems to be solved, positive examples that work well are used as a basis for the design process. The third stream, Needfinding highlights the importance of defining and understanding the long lasting needs of users throughout the development process, and to use these needs as the foundation for the requirement specifications (Ståhlbröst and Bergvall-Kåreborn, 2007). The methodology iterates between three activities: conceptualisation, realization and use of design scenarios, mock-ups, prototypes, and the finished system.

When engaging the participating older persons in giving their views upon how the design should be to fulfil their needs, we were inspired by the PAAR methodology, which can be regarded as a kind of 3rd generation action research. The PAAR methodology, like Appreciative Inquiry, focuses on accomplishments, strengths, successes and their root causes, so that success can be better understood and augmented. Using PAAR requires four strategic 'turns', meaning a change in direction from one way of thinking and practicing to another. The four turns are: 1) away from a preoccupation with changing behaviours and problem solving, towards the development of appreciative insights, understanding the causes of success in order to amplify those things that will help build a better future from the positive present; 2) away from self-learning (individualism and isolation) and towards collective learning, appreciative knowledge sharing and the use of new forms of communications technology; 3) away from one way of knowing and one perspective on truth to an acceptance of more pluralistic views of understanding human experience, and putting this knowing to good use; 4) away from reflective cycles and spirals and towards the use of a reflective learning (r-learning) framework, comprising four mutually supportive processes: developing an appreciative 'gaze'; reframing lived experience; building practical wisdom; and achieving and moving forward(Ghaye et al, 2008). This interaction between researchers and older persons is a prerequisite for developing the practical wisdom that will serve as a decision-aid to support self-management in health (Alpay et al, 2011). Building a strong, ongoing relationship with the older users in this project was crucial, since their involvement required a considerable time commitment on their part, as well as both physical and mental involvement (Bergvall-Kåreborn et al, 2010).

For the purpose to facilitate the transformation of the knowledge and experiences, which are informal and not easily translated into formal models to be executed by a computerized system, we apply a Meta-design perspective on the process and provide end-user development tools for modelling knowledge and designing the content of the system (Fisher and Herrmann, 2011). A Meta-design process acknowledges that the outcome is not a static product, instead a living knowledge system, which will need to be further developed since a full understanding of the users' needs and tasks will not be created at design time, and an individual's needs change over time. Moreover, this development should be possible to be conducted by the end-users. We consider both the older participants and the physiotherapy researchers as being end-users, since the physiotherapists see the potentials in using the system as a tool for providing therapeutic guidance and intervention. Moreover, the physiotherapy researchers are stakeholders as well, since the system can be used as a tool for mediating up-to-date evidence-based research findings. In this sense, the participants become both co-creators and end-users of the future and emerging application. Meta-design consequently supplements PAAR and Form-IT with an empowering end-user development perspective, enabled through the three levels of a Meta-design process: Designing Design (the conditions for creating an enabling end-user development environment), Designing Together (which complies with the participatory action research streams of PAAR and Form-IT), and Designing the "in-between" (essentially defining how the co-creative and evolutionary behaviour patterns can be sustained, to which both Form-IT and PAAR contribute).

2.2 Older Participants

The older participants were recruited at meetings arranged by senior citizen associations. The seniors were informed that their views and experiences were important input for the design and development of a novel digital application aimed to prevent falls. They were also informed that participation in the project meant that they could borrow either a smartphone or a tablet device during the project in order to test the application in their home environment. All who expressed an interest to participate (n = 38) were contacted by telephone and interviewed. Based on these interviews ten women and eight men were carefully selected in order to obtain a heterogeneous group with different experiences of technology, falls etc. The majority of the selected participants were former skilled white-collar workers and were, in general, fairly physically active. One third of the participants had fallen within the previous year, which reflect the rate of falling among the overall community-dwelling population. Two married couples were included, and four people lived alone. The mean age was 74.6 ± 3.5 years. Prior to the workshops the participants were divided into two groups. All group members, expect one woman, participated throughout the project and the attendance rate at all workshops and meetings was very high in both groups, around 90%. The study was approved by the Regional Ethical Review Board (Dnr. 2012-170-31 M). All participants provided informed written consent.

3. THEMES IN FOCUS FOR THE STUDY

Five physiotherapy researchers in the field of falls prevention participated in the project. They contributed with their expertise and domain knowledge, e.g., earlier research and existing evidence-based falls preventive exercise programmes already proven effective (the Otago Exercise Programme (Otago Medical School, 2003) and the Falls Management Exercise (Skelton and Dinan, 1999). Based on this knowledge, suitable exercises for the application were suggested. However, the exercise programmes needed to be expanded to include additional levels of difficulty and several new exercises. Besides this, there was a need to investigate how to introduce and structure these exercises in order to make the application appealing and motivate the older participants to engage in the exercises. It was also important to understand the future user's current knowledge about, and understanding of, fall risk and falls prevention. According to these prerequisites the workshops were planned based on four themes, which were considered crucial for the design of the application.

These themes were:

- Investigate the participants' experience related to fall
- Design exercises together with the older participants
- Explore motivational factors that can improve exercise adherence
- Design and develop the application together with the older participants

The first three themes are related to the conceptualisation phase of Form-IT, and create the base for realizing and using both test exercises and the application prototype. The design process was not linear, but rather iterative moving back and forth between conceptualisation, realization and use. During this process the application gradually developed through interactions between all participants. The older participants in this study were very engaged and expressed that they learned a lot during the meetings, and that the workshops inspired them to start doing fall preventive exercises themselves. The content of the workshops and the progress of the design phase are presented in table 1. In the subsequent sections, the workshops are described following the themes in focus. Finally, the resulting design of the application, and the design and formalisation process are described.

Table 1. *The main themes and activities of the first ten workshops, as well as activities carried out by the older participants between meetings.*

Workshop date and main themes	Activities at workshop	Activities between workshops
1. Oct. 2012 ***Experiences, Motivation***	Presentation of the project and participants. Focus group discussions: "Personal meaning of 'joy of movement' and balance."	Take photographs or collect pictures from papers of situations representing balance and joy of movement.
2. Nov. 2012 ***Experiences, Motivation***	Focus group discussions: "Personal meaning of 'joy of movement' and balance." Inspired by the photographs and pictures collected. Focus group discussion "Falls and consequences – what do you do to avoid them?"	Think about what motivates you to be physically active. How may an application for exercises look like?
3. Dec. 2012 ***Exercises, Motivation***	Lecture on balance and practical testing of balance exercises. Focus group discussion: "How can new technology inspire you to physical activity?"	Think about specific every day activities that you have changed your way of doing recently. Start using tablet or smartphone.
4. Jan 2013 ***Experiences***	Discussions in small gender divided groups: "Identify altered strategies in everyday activities, and how they are perceived."	Try out a free exercise application, and watch specified web links.
5. Feb. 2013 ***Motivation, Design and Development***	Activity: Take position in the room. Discussions in small gender divided groups. "Reflections on web links and applications tested. What would we like our app to be like?"	Use your smartphone or tablet
6. Mar. 2013 ***Motivation***	Working with personas.	Activity calendar. Suggestions for stealth exercises. Write your own persona description.
7. May 2013 ***Experiences, Motivation, Exercises***	Feedback and discussions on activity calendars and personas. Activity: Balance and strength exercises in groups.	
8. Jun. 2013 ***Exercises, Design and Development***	Test and feedback of the first prototype and exercises.	Use the prototype
9 Oct. 2013 ***Exercises, Design and Development***	Test and feedback of the second prototype and exercises. Visit a research lab for inspiration to start thinking about possibilities for feedback in the application.	Use the prototype
10. Nov. 2013 ***Design and Development***	Test and feedback of the third prototype with a new interface.	Use the prototype

3.1 Investigate Participants' Experience Related to Falls

During the first workshops the objective was to understand how the older participants conceptualized falls and fall risk and their strategies for avoiding falls in their every-day life. For these purposes the participants were encouraged to reflect on the concepts *balance* and *joy of movement* and what they meant for them. They were also asked to search for and select figures and photographs representing their perspective of these concepts. During the workshop the participants presented their different pictures followed by an open discussion. The discussion was led by an experienced researcher in an encouraging and positive atmosphere according to PAAR. The additional participating researchers took part in the discussions by adding questions and remarks, but were careful not to dominate or take focus from the participants' stories. One of the researchers had a specific responsibility to observe the participants from a gender perspective during the discussions and to take notes. All focus group discussions were recorded and transcribed verbatim and the content was analysed with a content analysis approach (Lundman and Graneheim Hällgren, 2008). Among many other insights, these discussions brought an understanding of the many needs; practical, mental, emotional, and social that may be involved in the process of developing fall risk awareness. (Pohl et al, 2014). This knowledge was above all important in order to understand how to give information to new users and market the application.

3.2 Design Exercises Together with the Older Participants

During the workshops related to developing exercises, practical sessions were conducted where participants could try out different exercises for balance and strength. In this way, they expressed how the exercises were experienced; which they liked and disliked, and why; how the exercises might be modified to be easier or more difficult; and what they judged as appropriate levels of difficulty. During these activities the older participants emphasized the importance of knowing why and how a particular exercise was beneficial. The older participants did also express preferences regarding details as the age, sex and clothing of the instructor and they all agreed that an inspiring and joyful instructor was important. Between meetings the participants were encouraged to carry on with the exercises and give feedback on how they managed. They were also asked to consider how the exercises could be woven into their daily activities, as well as to provide suggestions for new exercises.

3.3 Explore Motivational Factors that can Improve Exercise Adherence

The motivational aspects were central to the aim of this project, and as such they were part of nearly all the workshops. A range of different methods were used to elicit knowledge of what motivates older people to start and continue to exercise. The discussions in the focus groups were inspired by photographs that the participants brought, web links provided by the researchers, and try-outs of existing exercise applications as RunKeeper (FitnessKeeper Inc.), Moves (ProtoGeo Oy) and Workout Trainer (Skimble Inc.). In addition, more practical activities were conducted in which questions regarding exercise preferences were explored and discussed. Examples of questions could be: *Would you like to exercise alone or in a group? Would you like to exercise outdoors or indoors? Would you like to have your exercise calm or intense? Would you like to exercise with a scheduled programme or vowed in to your daily activities?* In these actives the answer alternatives were marked as areas in the physical room, and the participants were asked to go and stand in the area of their preferred view. Later they were encouraged to explain and argue for their choices.

Data from the first workshops were analysed with the help of content analysis and formed the basis for the construction of five fictional characters created to represent the different user types, i.e. personas. These personas were then presented to the participants, who rated how well the descriptions defined themselves and the way they preferred to do exercises. The participants did also write their own personas. These descriptions provided knowledge on how a falls preventive application may be designed to attract users with different characteristics and preferences. From this work it became clear that the participants had many diverse preferences but it was evident that many preferred to workout outdoors and to weave in exercises into their normal daily activities. Therefore, the resulting application contains both exercises for outdoor use, and so-called stealth exercises (that can be performed everywhere as part of everyday activities) and the possibility to create a personalized exercise programme.

The knowledge retrieved was used to develop a questionnaire on motivating factors in falls preventive programmes. This questionnaire was distributed to participants in our group present at workshop 9 (n. 16) and to a larger sample (n. 42) of potential users of the future application recruited at a “culture café meeting” at a local church. The questionnaire showed no major differences between preferences of the participants in our research group and the larger sample. In addition this questionnaire showed no particular differences in what men compared to women perceived as motivating factors.

3.4 Design and Develop the Application Together with the Older Participants

The participating older persons contributed significantly to the design of the application, especially regarding how the exercises are presented and to the user interface. Although there is currently no similar product with the same aim and target group available on the market, we could use other applications to inspire the older participants to get ideas. By trying out suggested existing physical training applications and exercise programmes in the form of web links, and later discussing their design, the participants expressed how they preferred to get their own exercises presented and organized. A very clear and simple layout of the interface was desirable, and the participants jointly decided to design the application based on short film clips in which the exercises are shown by an older person while verbal instructions are given. If the user wish to have more information about each exercise (e.g. more about why the particular exercise is important; how it can be adapted, for instance, in case of pain; or what to consider regarding safety issues) the information is easy accessible via buttons. All film clips are sorted into the categories “strength exercises”, “balance exercises” and “gait exercises”, and each category have a number of subgroups with exercises of varying difficulty. Users can easily find preferred and appropriate exercises and choose the ones to include in their own programme. The older participants did also contribute with concrete tips, which were integrated, about how to make exercises safer, and how to increase safety in everyday life. The researchers in physiotherapy contributed with new knowledge from research studies.

As a range of information and ideas were identified, discussed and prioritized, the researchers and participants created a perception of how a system supporting fall preventive strength and balance exercises might be designed and function. This informal knowledge, expertise and experience were transformed by the physiotherapists into formal information and process models using the ACKTUS platform (Lindgren and Nilsson, 2013; Lindgren et al, 2011). ACKTUS integrates a generic semantic model, based on models of human activity, the International Classification of Functioning, Ability and Health (ICF) and other medical terminologies, and can be expanded into higher granularity specific for a knowledge domain. None of the physiotherapists had prior experience in knowledge engineering, but were guided by a knowledge engineer in the process. As a starting point the physiotherapists researchers had a meeting with the knowledge engineer and began to structure the content and the flow of interaction, and a map with key concepts and their relations were drawn. Once the overall structure was created, the ACKTUS functioned as a tool for achieving the goal of developing a working prototype and the physiotherapy researchers themselves managed to model the content and design the interaction using the ACKTUS tool (figure 1), which allowed the participants to test hands-on.

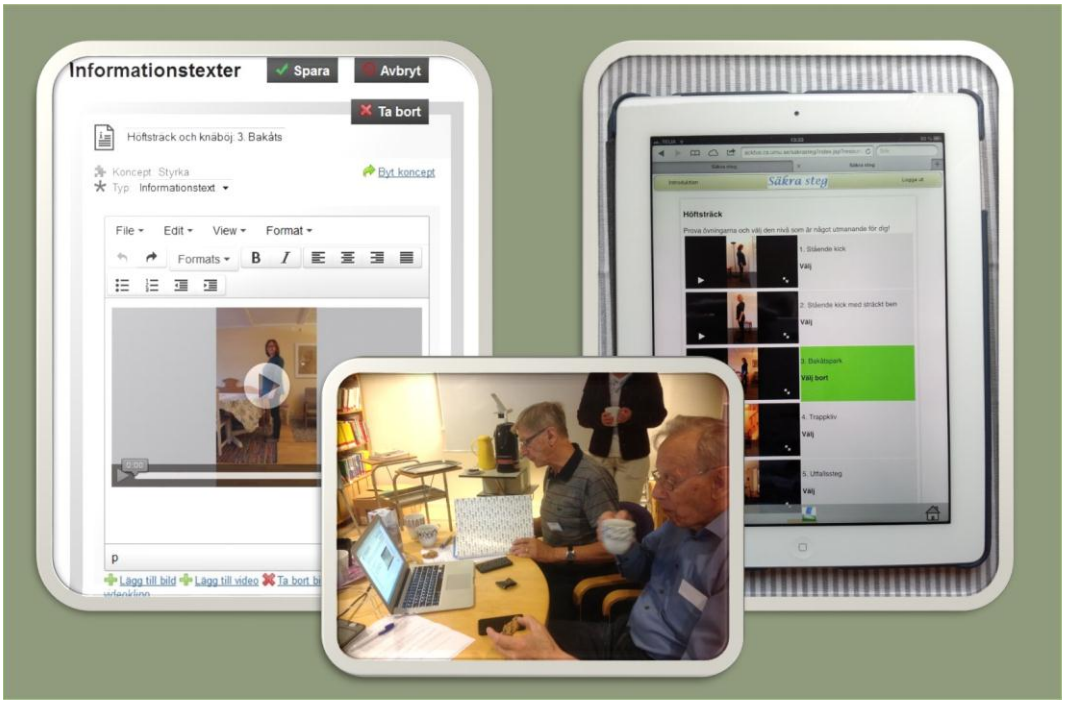

Figure 1. *The ACKTUS platform was used to model the content and design the interaction in the prototypes, which allowed the participants to test hands-on. Through ACKTUS the responsible physiotherapist researchers are able to modify and further develop the application.*

A first simple prototype of the future application, based on the ideas conformed during the workshops, was presented to the participants at the eighth workshop. The participants worked in groups exploring the prototype, while observed by the researchers, and shared their opinions and suggestions for improvements. The following workshops were dedicated to the refinement of the prototype in an iterative process. Between each workshop, changes were made to the interface based on the observed difficulties of the older participants to navigate in the programme. New exercises were gradually added for evaluation. An observation made during these workshop sessions was the wide variety of opinions and suggestions for change, where the participants often had contradictory opinions. As a consequence, a large degree of flexibility in the application was strived for.

The iterative procedure of prototype evaluation resulted in a process where both ACKTUS and the prototype were refined according to the requirements made by the users. This lead to a redesign of the user interface and the implementation of additional functionality in ACKTUS as well. By the use of ACKTUS the resulting application is modular, extendable, flexible and adaptable to the individual end-user. Moreover, the responsible physiotherapist researchers are able to modify the information and process models, and in this way further develop the application.

4. CONCLUSIONS AND FUTURE WORK

The combination of Form-IT and PAAR methodologies helped to create a positive atmosphere during the workshops, which greatly facilitated the interaction and likely contributed to the high engagement and attendance rate by the older participants. The methodologies encouraged the acceptance of pluralistic opinions, which was important because the participants had many diverse preferences. As a result the prototypes were designed with a high degree of flexibility. The participants expressed that they learned a lot during the meetings, and were inspired to start doing fall preventive exercises themselves. At the same time, the researchers felt that they learned a lot from the older participants as well. They got a deeper understanding of the older persons' understanding of fall risk and their views on falls prevention. The older participants also contributed to a greater understanding of exercise preferences and factors that might enhance motivation. Many of the things that emerged and later on was implemented in the application (e.g. outdoor exercises), was such that the scientists, despite their expertise, would never had thought of without the interaction with the older people. Consequently, the involvement of older persons was crucial in order to develop a falls prevention programme with the ability to attract older users.

The application of a Meta-design perspective resulted in an end-user development environment, which allows the end-users to continue to take an active part in further hands-on development of the prototype. The ACKTUS platform functions as a tool for this, by enabling the physiotherapist researchers to model and re-model both content and interaction. The older users can modify the content of their application by creating tailored exercise programmes, using the building blocks included by the physiotherapists. The resulting application is a dynamic application, easily adaptable to future needs and knowledge evolvement.

For future development of the application, the need for inclusion of motivating personalized feedback about progress over time, was discussed during the workshops. To achieve this, the user interfaces need to be enhanced with sensor information, carefully analysed and calibrated to the individual and the context, as a supplement to subjective evaluations. We have recently started work on including options for movement analysis, through the accelerometers already available in the phone or tablet, for these purposes. Another line of development is to transform the exercises developed for the application into an interactive video game using intelligent interface technology based on 3D sensors. In such a game the users would be able to see themselves doing the exercises as an integrated part of a game narrative, if desired, in a social context, and get both instant and summarized feedback. The application will be evaluated in future randomized controlled trials in order to study both method of implementation, user experiences, and the effect of the balance and strength exercises provided.

To summarise, the main contribution of this work is the application of the described theories and methodologies for achieving a socio-technical platform for engaging all stakeholders, both older adults and physiotherapists as domain experts and researchers, in a long-term collaborative "hands-on" design and development process, which provides sustainable and evolving knowledge-based instruments for prevention and rehabilitation.

Acknowledgements: Thanks to all the engaged participants who made this project so joyful and inspiring.

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User evaluation of a virtual rehabilitation system during reaching exercises: a pilot study

M Al-Amri[1], D Abásolo[2], S Ghoussayni[2], D Ewins[2,3]

[1]School of Healthcare Sciences, Cardiff University,
Heath, Cardiff, UK

[2]Centre for Biomedical Engineering, University of Surrey,
Guildford, Surrey, UK

[3]Gait Laboratory, Queen's Mary Hospital,
Roehampton, London, UK

Al-AmriM@cardiff.ac.uk, {d.abasolo;s.ghoussayni;d.ewins}@surrey.ac.uk

ABSTRACT

The aim of this paper was to evaluate the practicality of the Surrey Virtual Rehabilitation System (SVRS) for reaching exercises with children with CP. Five potential users or operators (two children with CP, a physiotherapist, and two clinical engineers) participated in the study. Using 11 closed-ended questions and an open discussion, the feedback collected indicates that the participants were generally positive about the practicality of the SVRS. Outcome measures obtained from data gathered during the session suggest that the SVRS can provide clinically relevant feedback on the performance of patients for themselves and their treating clinicians. In conclusion, the SVRS seems to be practical for rehabilitation purposes and further development and evaluation are warranted.

1. INTRODUCTION

Cerebral Palsy (CP) is a term given to a group of chronic non-progressive disorders in motor function resulting from damage that often occurs before the brain is fully mature (Bax et al, 2005; Gage, 1991). Motor system impairments are common in children with CP (Rosenbaum et al, 2007; Rosenbloom, 1995). The impairments lead to limitations in balance and coordination skills in children with CP, which can affect their everyday activities (Berker and Yalçin, 2010; Woollacott et al, 1998). Physiotherapy can provide a base to improve and/or preserve mobility and independence in children with CP for longer (Barber, 2008). This includes exercise programmes that focus on improving and maintaining ability to control and regulate postural stability, balance, and muscular strength (Berker and Yalçin, 2010). Postural control tasks require interaction between neural systems, to access position and control movements, and musculoskeletal systems to generate forces in order to achieve body movements (Chen and Woollacott, 2007; Shumway-Cook and Woollacott, 1995; Woollacott and Shumway-Cook, 2005). Improving the capacity to maintain posture while standing is one of the typical rehabilitation tasks for children with CP (Woollacott and Shumway-Cook, 2005). Positive results of physiotherapy can be obtained by high repetition of exercise programmes (Tsorlakis et al, 2004), which can be achieved whilst children are inspired and motivated to performing exercises in different situations (Tatla et al, 2013).

One possible approach of providing an intensive physical programme in a motivating and safe environment is the inclusion of Virtual Reality (VR) (Holden, 2005); it has become increasingly used for the rehabilitation of physical function in individuals with neurological conditions (da Silva Cameirão et al, 2011). The literature (Holden, 2005; Rizzo and Kim, 2005) shows that the potential effect of VR in rehabilitation is the capability to integrate the following important attributes for motor learning: intensity; motivation and engagement; and feedback on specific movements. However, most VR systems used in previous research (Galvin and Levac, 2011; Sandlund et al, 2008; Snider et al, 2010) had not been developed with rehabilitation in mind. Others have been designed specifically for use in rehabilitation, but these can be expensive, which has limited their use. In conjunction with a clinical team based in the rehabilitation centre in Queen Mary's Hospital, Roehampton, London, the Surrey Virtual Rehabilitation System (SVRS) has been developed by using existing facilities and basic components that can produce VR scene on a low-cost screen. The SVRS provides a variety of exercises for custom clinical use for children with CP (Al-Amri et al, 2011). As part of the development process, the need for postural control exercises was highlighted. Therefore two VR scenarios were prepared in order to evaluate the practicality of the SVRS during functional reaching exercises, as discussed in the following section. The primary aim of this study was to examine the practicality of the SVRS during reaching exercises through involving potential end-users or operators of the system in this development stage. For this work, the term practicality has been adapted based on the definition of usability by Nielsen (2003) and the ISO standard (Bevan, 2001) and used to describe: "*satisfaction, comfort, safety and, to some extent, utility*" (Al-Amri, 2012). The secondary aim was to quantify whether the motion data from the SVRS is feasible in evaluating user performance.

2. METHOD

2.1 Apparatus of the SVRS

Details of the first prototype of the SVRS can be found elsewhere (Al-Amri et al, 2011). Briefly, the SVRS includes two personal computers. The first computer (PC1) generates virtual environments that were developed using the Vizard Virtual Reality Toolkit (version 3.18.0002, WorldViz LLC, USA) and communicates with the second personal computer (PC2). The Qualisys passive infrared motion system (Qualisys AB, Sweden) using Qualisys Track Manager software (version 2.4.546) was used to track marker positions. This system ran on PC2 and transmitted motion data to PC1 via a TCP/IP communication protocol. To increase the safety of the SVRS, a function was implemented in Vizard to freeze the virtual world if PC1 did not receive complete motion data from PC2.

2.2 Participant Recruitment

The National Research Ethics Services (NRES) NHS Committee gave ethical approval to recruit children with CP who have previously visited the Gait Laboratory at Queen Mary's Hospital. Criteria for inclusion of children with CP in this study were: female or male; a consultant's diagnosis of diplegic or hemiplegic CP; aged between 12 and 17 years; Gross Motor Function Classification System (GMFCS) rating of level I to level III; and no evidence of photosensitive epilepsy. At this development stage of the SVRS, it was also decided to recruit representatives from professions typical of those who may have to operate the system in the future. An invitation was therefore sent to clinical engineers and a physiotherapist, who were not involved in any discussion about the SVRS development.

2.3 Investigation Procedure

The investigation was carried out in the Gait Laboratory at Queen Mary's Hospital, London. Informed consent from all participants was obtained. The participants were then asked to perform the following two functional reaching exercises:

The first exercise was developed to allow subjects to touch a virtual balloon in the virtual environment through controlling a virtual hand; this exercise lasted for a 2-minute period. In this scenario, participants performed the exercise at a standstill in front of the screen at a preset position on the floor. A pointer (see Figure 1) to which reflective markers were fixed was used to allow participants to control the virtual hand. Participants were asked to touch a virtual balloon that appeared on the screen in selected random positions in the virtual environment every 3 s and then return their arm to the original start position (arm relaxed and lying close to the trunk in a neutral position – Figure 1) once the balloon had been touched or missed. Balloon positions were normalised based on the participant's arm length and body height, which were used to maximise the distance of the balloon from the start position and the floor, respectively. The arm length was measured from the acromion to the end of the fingers. Participants were asked to repeat the test three times: the first, when balloons appeared on their dominant arm side, which meant they needed to touch a balloon by using only that hand; the second was similar but this time using the other hand; the third, when balloons appeared on both sides and participants were asked to use either hand as they considered appropriate. At the end of this test, the participants were asked to complete five closed-ended questions on a questionnaire.

In the second reaching exercise, participants were asked to control the virtual hand (following the procedure outlined above in the first exercise) to grab a virtual object by using the nearest arm and then to place it into the correct virtual barrel. These objects were generated as boxes and balls that were initially placed on a virtual table inside a virtual room (see Figure 2). With the aim of encouraging participants to move forward and sideways to reach the virtual objects, the depth position of these objects was generated to be equal to the participants arm length for six objects, plus up to 20 cm for the other three objects. Participants were instructed to move backward to the start position once they grabbed the object and then to move sideways to drop it in the correct barrel. For more motivation, the scenario allowed them to watch a cartoon film if they had placed all the virtual objects into the correct barrels within 120 s. During the task, a virtual projection screen extended down if they had dropped the first three virtual objects into the correct barrels in order to provide participants encouragement to continue performing the exercise. At the end of this test, the participants were asked to complete six closed-ended questions on a questionnaire, followed by an open semi-structured discussion between the first and the last authors of this paper, and in the case of the children with their parents/guardians. The overall aim of this discussion was to gather further information on their perceptions on the practicality of the SVRS during the exercises. Participants were asked during and at the end of each test whether they felt any discomfort from using the SVRS.

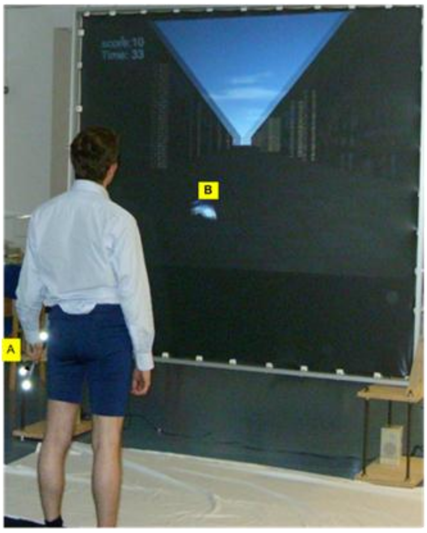

Figure 1. *An able-bodied volunteer using the SVRS to perform the first reaching exercise. A: pointer attached with reflective markers; and B: virtual hand in the virtual world.*

Figure 2. *An able-bodied volunteer using the SVRS to perform the second reaching exercise. A: during the actual test and B: a screenshot of the VR environment.*

2.4 Data Analysis

A questionnaire (Al-Amri, 2012) was developed in order to evaluate the first three components (satisfaction, safety, and comfort) of the practicality for each exercise. The open discussion was carried out in order to gather perspectives on the fourth component (utility) of the SVRS practicality.

Motion capture data from the participants were saved automatically in Microsoft Excel spreadsheets using code that was implemented in Vizard. These data were then used to quantify the following outcomes from the first exercise:

- Total number of balloons touched.
- Distance (normalised to arm length) that represents the path between the base of the hand and a virtual balloon.
- Time taken to cover the distance.

Whilst in the second reaching exercise, the following outcomes were selected:

- Distance (normalised to the arm length) that represents the path between the base of the hand and a virtual object on the table.
- Time taken to achieve the task.
- Amount of time taken to clear the virtual objects from the table.

3. RESULTS

A 14 year old girl with right CP hemiplegia (labelled as C1) and a 16 year old male with left CP hemiplegia (labelled as C2) participated in this study. C1 and C2 were classified as level I according to the GMFCS and receive on-going rehabilitation. A physiotherapist (labelled as A1) and two clinical engineering trainees (labelled as A2 and A3) also agreed to participate in this preliminary study. Participants A1-A3 had no past or present known issues with mobility and were considered to be able-bodied. Details of the participants are summarised in Table 1. A parent for each of the children with CP and a treating physiotherapist (PH) for C1 observed the testing.

Table 1. *Summary of general information about the participants. A1-A3 refers to able-bodied participants, while C1 and C2 refer to the children with CP.*

	C1	C2	A1	A2	A3
Height (cm)	168	177	180	190	169
Arm length (cm)	60	70	73	80	70
Vision deficiency	No	Yes	No	No	No
Dominant arm	Left	Right	Right	Right	Left

3.1 Perspectives on the First Reaching Exercises

After completing the three trials of the first reaching exercise, five closed-ended questions (see Table 2) were asked in order to examine the practicality elements of the SVRS as follows:

- Comfort was examined through the answer to Q1, and Q2.
- Satisfaction was tested by Q3.
- Safety was evaluated through the response to Q4, Q5, as well as the observation by the investigators.

For each question participants were asked to choose one of five possible responses ranging from ‘Awful’ to ‘Brilliant’. For analysis purposes responses of ‘Good’ or ‘Brilliant’ were considered to be positive. The responses of each participant are presented in Table 2 and these show that the participants were positive about the Comfort, Satisfaction and Safety of the SVRS for this exercise.

Table 2. *The participants’ responses to the first five closed-ended questions. A1-A3 refers to able-bodied participants, while C1 and C2 refer to children with CP.*

	Brilliant	Good	OK	Poor	Awful
Q1. I would rate my ease in controlling the virtual hand as:	A1,A3	C1, C2,A2	None	None	None
Q2. My ability to touch the virtual balloons was:	C1,A1,A3	C2, A2	None	None	None
Q3. I would rate my enjoyment in touching the virtual balloons as:	A2	C1, C2, A1, A3	None	None	None
Q4. I thought my safety when touching the virtual balloons was:	C1, C2, A1,A2,A3	None	None	None	None
Q5. My overall confidence when touching the virtual balloons was:	C1, C2, A1	A2,A3	None	None	None

The outcome measures results are summarised in Table 3, which indicate that the participants moved their dominant arm from the base to touch balloons within a range of median distance between 52 and 78 (% of a participant’s arm length). The range of the median time that was taken to cover that distance was between 1.2 s and 1.9 s. For children with CP, C1 and C2 touched 18 balloons out of 19 with their dominant arm covering a median distance of 52% and 65% of their arm length, respectively. For able-bodied volunteers, the results show that A2 moved his left dominant arm from the base to touch balloons in the shortest median distance in comparison with A1 and A3.

In the non-dominant trial, the results show that C1 moved the affected arm from the base to touch balloons at a median distance of 19% (of actual arm length) more than distance used by C2. A2 moved the non-dominant right arm at least a median distance of 5% (of actual arm length) less than what A1 and A3 did to touch balloons, within a shorter time. In the third trial, the participants swapped the pointer between both hands to touch balloons that appeared on both sides.

Table 3. *Results of outcomes during the first reaching exercise.*

Dominant Arm Trial						
Outcomes		C1	C2	A1	A2	A3
Normalised Distance	Median (% of actual arm length)	52	65	78	65	68
	Range (% of actual arm length)	20– 99	28-87	22-97	36-95	25-97
Time taken to touch a balloon	Median (s)	1.3	1.2	1.9	1.2	1.8
	Range (s)	0.5 – 2.2	0.7-2.3	1.5- 2.3	0.8-1.8	0.7-1.8
Number of balloons touched	Score (out of 19)	18	18	19	19	19
Non-Dominant Arm Trial						
		C1	C2	A1	A2	A3
Normalised Distance	Median (% of actual arm length)	82	63	79	74	86
	Range (% of actual arm length)	51– 99	37.0-94.0	44-99	18-92	21-98
Time taken to touch a balloon	Median (s)	1.3	1.9	2	1.3	2
	Range (s)	0.8-1.8	1.2-2.6	1.8-3	0.8-2.3	0.8-2.5
Number of balloons touched	Score (out of 19)	18	17	19	19	19
Both Arms Trial						
		C1	C2	A1	A2	A3
Normalised Distance	Median (% of actual arm length)	68	60	72	76	65
	Range (% of actual arm length)	30– 99	20-90	58-91	58-94	37-92
Time taken to touch a balloon	Median (s)	1.3	1.5	2.2	1.6	1.5
	Range (s)	0.6 – 1.9	0.8-2	1.6-2.5	1.2-2.3	0.8-2.1
Number of balloons touched	Score (out of 19)	18	17	19	19	19

3.2 Perspectives on the Second Reaching Exercises

For the purpose of evaluating the practicality elements of the SVRS during the second reaching exercise, six closed-ended questions (see Table 4) were asked:

- Comfort was examined through the answers to Q6, Q7, and Q8.
- Satisfaction was tested by Q9.
- Safety was evaluated thro ugh the response to Q10, Q11, as well as the observation.

The results presented in Table 4 show that the perspectives of the children with CP on the practicality elements of the SVRS during this exercise were not notably different from those of the able-bodied volunteers. Both groups were positive about the Satisfaction and Safety of the SVRS, and there was a mix of positive to OK responses for the Comfort aspect.

The results for the outcome measures for the participants during the second reaching exercise are summarised in Table 5. The shortest median normalised distance for grabbing an object was achieved by subject A2 (71 %), followed by C2 (84 %). The shortest completion time for the task was 33 s and this was achieved by A3, followed by C1 (37s).

Table 4. *The participants' responses to the six closed-ended questions relating to the practicality during the second reaching exercise. A1-A3 refers to able-bodied participants, while C1 and C2 refer to children with CP.*

	Brilliant	Good	OK	Poor	Awful
Q6. I would rate my ease in controlling the virtual hand as:	A3	A2	C1, C2, A1	None	None
Q7. How easy was it to reach for the balls and the boxes that were on the table?	None	A2 A3	C1, C2, A1	None	None
Q8. My ability to drop the balls and the boxes in the correct container was:	None	C1,C2,A1,A2,A3	None	None	None
Q9. How enjoyable was it to clear the balls and the boxes from the table?	None	C1,C2,A1,A2,A3	None	None	None
Q10. I thought my safety when clearing the balls and the boxes from the table was:	C2,A2,A3	C1, A1	None	None	None
Q11. My overall confidence when clearing the balls and the boxes from the table was:	A3	C1, C2, A1,A2	None	None	None

Table 5. *Results of outcomes during the second reaching exercise.*

		C1	C2	A1	A2	A3
Normalised Distance	Median (% of actual arm length)	101	84	102	71	107
	Range (% of actual arm length)	26-156	24-129	36-151	46-146	33-179
Time taken to reach an object on the table	Median (s)	2.1	2.2	2.6	2.0	1.6
	Range (s)	1.0-4.5	1.1-4.4	1.2-6.6	1.2-3.1	1.2-2.8
Completion Time (s)		37	49	41	43	33

3.3 Perspectives on the Reaching Exercises

In the open discussion with the participants, only A1 and the parent of C1 commented on these exercises. First of all A1 reported that the explanation of how to perform the second exercise was not clear. However, A1 believed that the scenarios would be helpful for rehabilitation purposes - to improve reaching while maintaining balance during standing. She also suggested that for the first exercise there should be a way to ensure that subjects return their arm back to the correct starting position before touching the next balloon, e.g. through messages on the screen. The parent of C1 commented that the scenario motivated his daughter, however, he also suggested running the scenario at different speeds, which could make it more challenging. The physiotherapist for C1 (PH) was pleased with the motivation shown by C1 during the exercises. PH made positive comments about the utility of the SVRS in rehabilitation for children with CP noting that the SVRS may benefit the rehabilitation of children with CP and it would be helpful to have such equipment in the clinical environment. She also wondered whether automated performance measurement for each user in each session could be done in such a way as to provide immediate feedback to patients. None of the participants reported any discomfort when using the SVRS.

4. DISCUSSION AND CONCLUSIONS

The purpose of the present study was to evaluate the practicality of the SVRS and the feasibility of using motion data to provide performance feedback to end-users. In the first exercise, the results show that the children with CP and the able-bodied participants were positive about the first three elements of the practicality of the SVRS. The results presented in Table 3 suggest that each participant used a different approach to touch the balloons. It was also noticed that participants did not always return their arm to the required starting position though, which might be a key reason for differences in the results of outcome between individuals; none of the participants had difficulties with holding the pointer. Despite these limitations, the results generally show the feasibility of the SVRS to assess individual performance.

In terms of the perspectives on the practicality of the SVRS during the second reaching exercise, all participants were positive about the satisfaction and safety of the SVRS, but the results show that while A2 and A3 were positive about the comfort of the SVRS, the children with CP and A1 were not. This difference might be due to the fact that children with CP found it harder to control the hand while they were required to make movements. In the case of A1, the task was not clear to her as she commented afterward on the lack of the explanation that was provided. For instance, making movements forward, backward, and to both sides were required in order to reach the virtual objects. Swapping the pointer between the arms to reach the nearest object and barrel was also encouraged as part of completing the task. To drop the grabbed object, the participant had to move it to touch a small red box that was placed on the top of each barrel. During the observation, it was noticed that only C2 and A2 performed the task based on these instructions, which reflect the median distance the arms moved to grab objects as can be seen in Table 5.

For the outcome of the discussion in order to evaluate the "utility" of the SVRS, the two physiotherapists (PH and A1) felt that the scenarios may challenge children with CP to develop a strategy in order to complete the tasks successfully. This may improve not only postural control and balance but also the ability to conceive and achieve different actions, which may have a positive impact on the ability to improve daily life activities.

There were several limitations inherent in this study. The small sample size was the main limitation and so it is possible that the results might have been altered with larger sample size. In addition, the current VR scenarios did not ensure subjects performed the exercises as was explained, which will have impacted on the differences seen in the results.

In conclusion, the results are encouraging, but further modifications and investigations need to be considered in the future work. For example, in the future design of these exercises, an algorithm to ensure that subjects will return the hand to the origin base will be implemented.

Acknowledgements: The authors would like to thank the clinical team in the Gait Laboratory at Queen Mary's Hospital for their advice, support, and comments on virtual scenarios and their help during data collection. We would also like to thank the children and their parents for their time, enthusiasm and feedback.

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Locating objects in virtual reality – the effect of visual properties on target acquisition in unrestrained reaching

V Powell, W A Powell

School of Creative Technologies, University of Portsmouth,
Winston Churchill Avenue, Portsmouth, UK

vaughan.powell@port.ac.uk, *wendy.powell@port.ac.uk*

www.port.ac.uk

ABSTRACT

Locating objects in virtual space is not the same as locating them in physical space. The visual properties of the virtual object can affect the perception of its spatial location, and hence the ability to accurately co-locate the hand and the object. This paper presents an investigation into the effects of object geometry and proximity brightness cues on the time-to-target of a virtual reality reaching and grasping task. Time-to-target was significantly affected by object geometry, but not by brightness cues. We conclude that object geometry needs to be carefully considered for applications where accurate co-location of hand and object are important.

1. INTRODUCTION

With rapid advances in technology and diminishing costs, Virtual Reality (VR) is emerging as a rehabilitation tool which is able to engage patients and improve treatment compliance and outcomes (Bryanton et al, 2006; Rizzo and Kim, 2005; Thornton et al, 2005). There is evidence that it can provide distraction from pain (Hoffman et al, 2004, 2000, 2003, 2001) and aid neurological and physical rehabilitation (Jack et al, 2001; Kizony et al, 2003a; Merians et al, 2002; Piron et al, 2001; Sveistrup et al, 2003).

Virtual Reality can provide a rich visual context with meaningful ecologically valid activities which support the higher functional tasks that promote motor learning. Furthermore, VR offers the ability to present elements within the virtual environment (VE) whose visual perception and interactive properties can be manipulated to have precisely determined characteristics, or even discrepancies, in order to subtly influence participant behaviour and perception (Murray et al, 2006; V. Powell et al, 2010; W. Powell et al, 2006, 2007, 2013).

However, whilst it is recognised that movement and perception in a virtual environment is not directly equivalent t to the real world, there is little work to date investigating the ways in which upper limb movement is impacted by the design of the VE, and thus a lack of information to support designers to create optimised VR applications which support the rehabilitation goals whilst minimising fatigue or frustration caused by visuo-motor mismatches during task performance.

2. REACHING AND GRASPING IN VIRTUAL REALITY

Visual compression of distances in VR is a well documented issue (Armbruster et al. 2008; Frenz et al, 2007) and this can influence the user's ability to accurately locate and reach an object in virtual space. Whilst some evidence suggests that practice and training can afford some adaption to this distance compression (Jones et al, 2009), nevertheless it is a potential source of frustration and difficulty, which may add to the physical and cognitive load when using VR for physical rehabilitation. Thus, to facilitate the creation of ecologically valid and task-relevant virtual rehabilitation environments, it is important to understand the ways in which the visual properties of an object may affect the ability to locate it in virtual space, and how this can be used to optimise the design of upper limb reaching and rehabilitation tasks.

From a clinical practitioner's perspective, the ability to motivate patients to reach with their arms and hands, and intercept to a predetermined point in space has notable rehabilitation value. In order to achieve this, a number of studies have used spheres as target objects in reaching tasks in the evaluation of the potential for VR in a rehabilitation context (Armbruster et al, 2005, 2008; Kizony et al, 2003b; Loomis and Knapp, 2003; Viau et al, 2004). Spheres have a natural implied narrative context for goal orientated tasks as they readily encompass balls to hit or catch in sporting simulated games, or bubbles or balloons to pop, and this can be important for engagement with physical rehabilitation and immersion in VR (Craig, et al, 2009). An alternative approach that some VR applications often find appealing is to render 3D objects as realistically as possible to enable the knowledge of the object itself in the real world to convey a sense of perspective and distance (Goldstein, 2002), and to enhance the immersion or sense of presence (Kauffman et al, 2008; Subramanian et al, 2007). It remains unclear however what impact these approaches have on the user's perception of target location and distance to interception, and hence their reaching performance. Indeed, abnormal reaching behaviour has been noted during object acquisition tasks in VR, but the underlying factors causing this aberrant movement are not well understood. Where movement differences are noted in VEs compared to normal environments, the possible explanations given often include issues with spatial perception of the target object (Knaut, et al, 2009; Magdalon, et al, 2008, 2011; Viau, et al, 2004). In addition some of the studies indicate behaviours that are likely to implicate properties of the target object itself and even demonstrate differences in behaviour between objects with different characteristics (Magdalon, et al, 2008, 2011). This latter point is compelling as it suggests that the visual representation and properties of target objects within the VE and the visual cues they convey to the user might be responsible for altering motion patterns. This has significant implications for rehabilitation or neuropsychological tasks in VR that involve reach to grasp actions, and suggests the need to establish its potential effects and how to ameliorate them. It also raises the question of whether object properties could be optimized to given tasks and, furthermore, whether their properties could be manipulated to influence motion behaviours to further enhance rehabilitation.

In the majority of studies published to date the type of virtual target objects used for reaching tasks varies widely, and there has been little work exploring the effect of the visual characteristics of these different objects on target acquisition time or reaching behaviour. Previous studies have indicated that whilst users can locate the general position of a virtual object in peri-personal space (Armbruster et al, 2008), they may have issue with spatial perception within a VE. This may become more pronounced during the final corrective motions to hand trajectory when ascertaining the precise location of the object in the terminal or deceleration phase for reaching and grasping (Hu et al, 2002; Kuhlen et al, 1998; Madison et al, 2001; Magdalon et al, 2011; V. Powell et al, 2010).

If altering the visual properties of an object can improve the ability to locate the object in virtual space then this may improve task performance and improve the rehabilitation outcomes. In addition this may improve participant confidence, immersion and engagement with the given tasks and avoid undesirable and atypical reaching strategies (V. Powell, 2013). Therefore it is important to establish which visual properties affect the time taken to locate the object in virtual space in order to inform better design of a virtual environment (VE) for upper limb rehabilitation. It would seem reasonable to start by evaluating the more commonly used target objects alongside objects with alternative geometries.

It has previously been demonstrated that the visual properties of target objects could influence the ability to accurately reach the object in virtual space (V. Powell et al, 2010), but the relatively small sample size (n=13) and large number of experimental conditions (n=8) limited the conclusions which could be drawn from statistical analysis of the data. Nevertheless, it was clear from this preliminary work that manipulating the visual properties of a target object could impact the time to target in reaching tasks, potentially reducing the biomechanical load imposed by "loitering and fishing" for targets with ambiguous depth cues.

The study presented in this paper builds upon insights gained from this earlier work, presenting users with a virtual apple-picking task using three different objects as reaching targets (Figure 1):

1. An apple - to provide an ecologically valid realistic model with visual narrative to the orchard scenario and with object familiarity and relatable scale.
2. A sphere - the most commonly used simple object in published upper limb VR scenarios (usually representing balls or bubbles).
3. A 20 sided polygon (icosahedron) - a low polygon model with inherent visual depth cues due to intra object landmarks for surface motion parallax, and occlusion or dissocclusion of surface and edge geometry during relative movement.

It is reasoned that a reduction in "loitering" or time to target, in the deceleration phase of reaching, may indicate a confidence in the user's perception of the spatial location of the virtual target objects, improving movement efficiency and thus better supporting rehabilitation goals. This study thus sets out to determine the relative impact on loiter time of the visual cues inherent in different target object geometries, and furthermore whether increasing brightness cues on proximity will enhance or detract from this.

Figure 1. *The three object shapes used in the study.*

3. METHOD

The experiment was a repeated-measures within-subjects 2 x 3 factorial design (shape x brightness), with the objects either staying constant, or increasing brightness on proximity, for each experimental condition. The independent variables were object shape / parallax cues and brightness change (Table 1). Time in milliseconds from object proximity to object acquisition (loiter time) was the dependent variable.

Table 1. *The experimental conditions for the reaching study.*

	Apple	**Sphere**	**Polyhedron**
Shape only (no brightness change)	Condition A	Condition B	Condition C
Increase brightness on proximity	Condition D	Condition E	Condition F

A power calculation conducted on the basis of the data from the previous experiment (V. Powell et al, 2010), and twenty nine healthy volunteers (17 male, 12 female, age 19-46) participated in this experiment. The tasks were carried out in a Virtual Reality laboratory with a 'Virtual Orchard', created in 3D Studio Max and rendered into an interactive format using Open Scene Graph (Figure 2).

Figure 2. *The virtual orchard used in the study.*

Participants were equipped with Ascension Technology (Flock of Birds) magnetic motion trackers attached to the antero-lateral margin of the acromion process of the scapula, and on Lister's tubercle of the wrist on the dominant hand, and their movements were tracked in the Virtual World with a virtual representation of the same hand.

The target objects were asymmetric apples (1500 polygons), spheres (960 polygons) or icosahedrons (20 polygons), all were 10cm in diameter (Figure 1).

Ten objects were presented for each condition. The target object positions were varied on the horizontal and vertical axis and in depth from the screen, and the same configuration was maintained for each condition.

It has been noted that colour has a differential effect on depth perception, with a general trend to overestimate distances to red targets and underestimate distances to green targets (Gentilucci, et al, 2001). No distinct colour has been identified with veridical distance estimation. Therefore to minimise the confounding effect of colour, each variant of the object was rendered in both red and green with non-uniform surface material textures to ensure that any observable differences in motion were due to the object shape.

Virtual baskets provided both a narrative context and a means of completing the interactive task with alternating movement patterns at the shoulder to prevent excessive repetition. They were initially displayed on screen, and once their role had been explained to the participant they were displaced to their position on the participants back. The participants dropped each ‘apple’ into the virtual basket after successful object acquisition.

The virtual camera was set to match the starting position of the participant, with a field of view of 100^{o} and a starting height of 1.6m above the ground plane. The stereoscopic scene was projected onto a 4.5m x 2m display screen using a pair of Christie 7700 Lumen projectors with polarising filters. To minimise visual distraction, the room was darkened for the experiment, with the main light source being the display screen itself. An eye-hand vector camera tracking algorithm described previously (V. Powell and Powell, 2010) was used to orient the virtual camera. The target objects were projected stereoscopically in negative parallax (i.e. to appear as if they are in the room).

If the inherent visual cues of the target object are to influence the perception of the final spatial determination of that object, it would be reasonable to expect this to be most evident in the deceleration phase of reaching and grasping actions. Therefore based on the observations of Kuhlen, et al, (1998) the “loiter time” is taken from hand proximity to the object (30cm), to object acquisition. This “loiter time” or time to target is the primary dependent variable used in this study. The “loiter time zone” initiated recording as soon as the reaching hand passed within it (and paused if the hand left the zone) recording the cumulative duration it took for the hand to pass through the zone and successfully contact the target object.

3.1 Procedure

Participants were introduced to the physical environment of the VR suite and guided through the dynamics of the task. The magnetic sensors were then attached to the wrist and shoulder and trailing wires secured. Participants were asked to repeat the shoulder range of motion actions to ensure they were free to do so unhindered.

At the start of each experimental trial the participants had a non-interactive view of the “Orchard” with the baskets in view. The starting position of the sensors was recorded and used to initialise the camera view in the virtual scene, which was dynamically linked to the actions of the participant. The hand movement of the participant was mapped to a virtual representation of the dominant hand.

A demonstration object (of the same type and visual behaviour as the test condition) was presented at eye height 2m in front of the participant. Data recording was initiated after the demo object had been successfully acquired and dropped into the virtual basket.

For each condition, the ten test objects (5 green and 5 red) were displayed one at a time (alternating colours) in preset locations within the participant’s field of view. To avoid pre-planning the next move, each object had to be acquired and dropped successfully before the next object was revealed. The time from object proximity (30cm from the object centre) to object acquisition was recorded for each test object.

For conditions A-C the object brightness remained unchanged throughout the trial. For conditions D-F, the brightness automatically increased once the hand reached the loiter zone.

4. RESULTS

A mean value was calculated for the time-to-target for the 10 objects in each experimental trial, using the time in ms from object proximity (30cm from the centre of the object) to object acquisition (Table 2) . In order to accurately reflect the wide variations in performance in a normal human population no data filtering was used in this study.

Table 2. *The time-to-target in ms for each experimental condition (StDev in brackets).*

	Apple	**Sphere**	**Icosahedron**
Shape only (no brightness change)	3106*(1966)*	3883*(3388)*	3006*(1700)*
Increase brightness on proximity	2957*(1748)*	4140*(4059)*	3127(*1893)*

A repeated measures 2-way ANOVA (shape x brightness) demonstrated a significant effect of shape on time-to-target ($F_{(2,56)}=3.62$, $p<0.05$), but no significant effect of brightness on time-to-target ($F_{(1,28)}=0.09$, $p=0.77$).

Mean times-to-target durations were compared for the brightness changing conditions and the constant brightness conditions. There was no significant effect of brightness on time-to-target ($F_{(1,28)}=0.09$, $p=0.77$).

Post-Hoc testing revealed that time-to-target was significantly longer in the sphere condition compared to the icosahedron condition ($p<0.05$) and also longer compared to the apple condition, although this did not reach 5% significance level ($p=0.07$). There was no significant difference between the icosahedron and apple conditions (Figure 3).

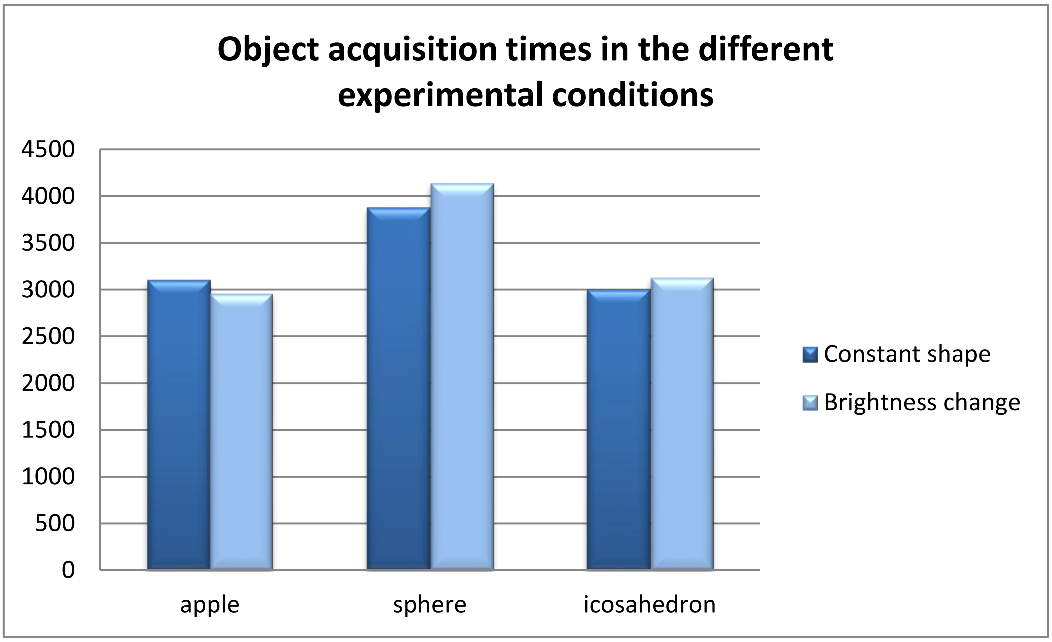

Figure 3. *Mean Time-to-target (ms) for each of the 6 experimental conditions.*

5. DISCUSSION

The results from this study confirm that the geometry of a target object significantly affects the time spent in the terminal phases of object acquisition. The sphere, although a commonly used object in VR upper limb tasks, demonstrated the longest loiter times overall, and the difference between it and both the apple and the icosahedron was statistically significant. Interestingly there was no statistically significant difference between the apple and the icosahedron, suggesting that the unconventional simple geometric target object with little real world familiarity or sense of inherent scale as an interactive object, performed as well as the modeled target object based on a real world object that many individuals should be familiar with.

There was no significant effect of the brightness changing condition on time to target, suggesting that the absolute depth cues provided by object geometry, in peripersonal space, was a more important design consideration.

This study supports the findings of the previous smaller study regarding the poor performance with spheres as target objects (V. Powell et al, 2010), and confirms that the common practice of the use of spheres as target objects in VR tasks that involve reaching and grasping is potentially a confound for research outcomes and possibly deleterious for rehabilitation goals. The sphere geometry has been demonstrated to require a longer duration for the deceleration phase of reaching.

No significant difference was found between icosahedrons and the modeled apples as target objects. This suggests that for simple Virtual Environments, that do not have an imperative need to attempt photorealism, low polygon models can be found that will provide sufficient depth cues for determining spatial location in reaching and grasping tasks without the need for more detailed modeling. The simpler geometric object, at 20 polygons, requires less than 2% of the computational load of the apple object, which could have significant implications for software performance, particularly in applications with multiple target objects. The similarity between the performance of the low-poly icosahedron and the apple may be due to the fact that both objects have visual variation at different angles and distances, providing richer depth cues than the symmetrical spheres. There might also be a trade off with the apple providing natural depth cues through familiarity and scale, whilst the icosahedron which effectively lacks a relative scale or familiarity in the context of its environment does however provide richer depth cues through its intra object landmarks that provide surface motion parallax, along with the occlusion or dissocclusion of its surface and edge geometry during relative movement. The spheres however, do not typically provide any of these spatial cues (Figure 4).

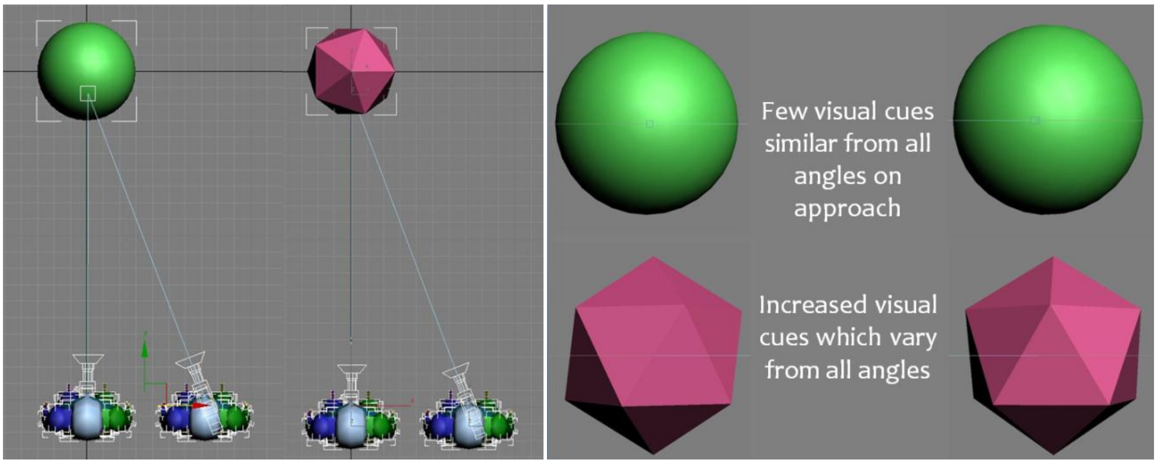

Figure 4. *Varying viewing position (left) provides additional visual cues to support accurate depth perception with the icosahedron, but not with the sphere (right).*

The manipulation of target object geometry had a more significant effect on time to target than altering brightness, however it should be noted that the transitional brightness change did not attempt realism but rather operated as a proximity cue as seen in a number of computer games. In this regard it would appear to be ineffective in a VR setting and perhaps further investigation of more realistic brightness changes in response to global illumination or local intense light sources might be worth further investigation, as might the reflective nature of the target objects surface material.

Although shadows and interreflections have previously been found to be significant cues when determining the accurate perception of distance between two object surfaces (Hu, et al, 2002), these are rarely rendered in VR action tasks for physical rehabilitation, and are computationally demanding to deliver with real time interaction in any extensive virtual environment. Until VR achieves near veridical portrayal of objects, even with the addition of shadows and interreflections, depth cues may need augmentation. Further investigation of object properties to facilitate absolute spatial location and subsequent movement behaviours is being undertaken.

It should be borne in mind that these results are from a population of healthy individuals, and further investigation is proposed in order to establish the effect of target object geometry among a population with shoulder restriction and pain. Nevertheless, it is relatively simple to manipulate object geometry to facilitate reaching to grasp rehabilitation tasks or to support more generic upper limb exercise outcomes, and it is certainly worthy of consideration during application design. Selecting object geometries which support accurate spatial location may help to reduce frustration and fatigue in VR upper limb tasks.

This study aims to facilitate informed design and highlight an often overlooked component of VR. Where practical, virtual rehabilitation application design should have some consideration of target object type in relation to the desired application goals. A summary of functional task requirements and their respective suggested preferences for potential target object visual properties is offered for consideration (Table 3).

6. CONCLUSION

This study confirms that object shape has a significant effect on the time taken to locate and grasp a virtual object in 3D space, and that spherical balls and bubbles often used in upper limb rehabilitation games may not be the most suitable object shapes, prolonging the time taken to locate the object in space, and consequently increasing the risk of fatigue or disengagement during task performance.

Although there is much work still to be done before fully optimised virtual tasks can be designed, it is clear that it is possible to improve task performance without increasing computational load on the VR system by implementing some simple changes in the design of the target objects.

Table 3. *Suggested object characteristic preferences for action tasks.*

Functional Task requirements	*Preferred Target Object Characteristics*	*Least desirable Target Object Characteristics*
Pointing to target, Interception of target, Touching target. Where active and engaging movement needs to be encouraged and precise motion is not critical to outcomes	Any, Spheres are simple to model and provide a narrative context for the user to relate to and engage with the task. Non uniform surfaces are preferable particularly for moving objects	Abstract objects with little or no narrative engagement or those with high computational demand.
Grasping or surface contact tasks with precision in a close constrained space where objects are in close proximity.	Objects with rich visual spatial cues e.g. either icosahedrons or realistic modeled objects with functional familiarity, textures, interreflections and shadows.	Spheres and objects that present the same visual information throughout different viewing angles.
Reaching and Grasping targets at varying distances, without constraints on participant movement, relating to tasks with specific ecologically valid real world outcomes.	Objects with contextual familiarity and relevancy e.g. Realistically modeled representations of real world objects.	Spheres, abstract icosahedrons and objects with high computational demands for visual proximity cues.
Reaching and Grasping targets at varying distances, without constraints on participant movement, relating to tasks with specific functional movement outcomes or accuracy in spatial perception	Objects with rich visual spatial cues and low computational demands e.g. Icosahedrons	Spheres or shapes that provide minimal motion parallax cues on approach or realistically detailed models with high computational demands.

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Subjective perceptions when using motion tracking systems – a comparison among healthy subjects, individuals post-stroke, and therapists

R Lloréns[1,2], A Borrego[1], E Parra[1], V Naranjo[1], E Noé[2], M Alcañiz[1,3]

[1]Instituto Interuniversitario de Investigación en Bioingeniería y Tecnología Orientada al Ser Humano, Universitat Politècnica de València, Camino de Vera s/n, 46022 Valencia, SPAIN

[2]Servicio de Neurorrehabilitación de los Hospitales NISA Valencia al Mar y Sevilla Aljarafe, Fundación Hospitales NISA, Valencia, SPAIN

[3]Ciber, Fisiopatología Obesidad y Nutrición, CB06/03 Instituto de Salud Carlos III, Av. Sos Baynat s/n, Univesity of Jaume I, 12071 Castellón, SPAIN

rllorens@labhuman.com

[1]*www.labhuman.com*, [2]*www.neurorhb.com*

ABSTRACT

Different tracking technologies allow users to interact with virtual reality environments. Most research regarding tracking systems has focused on studying their performance parameters, mainly accuracy. However, even though subjective parameters also determine the responses evoked by the virtual reality experience, least efforts have been made to study their influence. The subjective perceptions of healthy subjects, individuals post-stroke, and physical therapists after using three tracking technologies (optical, electromagnetic, and skeleton tracking) to interact with a virtual rehabilitation exercise were collected via questionnaire. Results showed that subjective perceptions and preferences are far from being constant among different populations, thus suggesting that these considerations, together with the performance parameters, should be taken into account when designing a rehabilitation system.

1. INTRODUCTION

Virtual Reality (VR) can recreate synthetic environments that can be tailored to provide specific sensory stimulation in different channels. However to immerse individuals in an alternative reality, not only the stimulation is required, but also the virtual environment (VE) must react in a similar way as the real world, at least in certain aspects (Bangay et al, 1998). Interaction with the VEs has been a technical challenge through the years. In order to detect and transfer the users' movements to the VE, different tracking solutions have been proposed. Tracking systems estimate the location and orientation of known targets with six degrees of freedom and transfer the data to the virtual world in real time (Burdea et al, 2003). Traditionally, three main physical principles have been used to locate the targets, therefore classifying the tracking systems as either optical, electromagnetic, or inertial (or hybrid solutions combining the mentioned mechanisms).

Recent advances in technology have given rise to cheaper motion tracking solutions based on depth sensors, as the Microsoft® Kinect™ (Microsoft®, Washington) or the ASUS® Xtion Pro (ASUS®, Taipei), both equipped with the PS1080 chipset (PrimeSense™ Ltd, Tel Aviv). According to the previous classification, these solutions can be considered as optical-based, because they estimate the depth information of a scene, but they are complemented with a statistical method to estimate the main joints of the human silhouettes present on the captured scene (Shotton et al, 2011). Even though the classical definition of tracking systems requires the location of a target with six degrees of freedom, the location of the joints provided by the skeleton tracking is enough to interact with a great number of VE. The low cost of these devices, their comfort (no wearable sensors are needed), and their off-the-self availability have facilitated their widespread use (Llorens et al, 2012).

All the tracking technologies present different characteristics that are inherent to the physical principle in which they are based on. Consequently, a tracking system can be defined by some parameters, such as accuracy, jitter, drift, and latency (Burdea et al, 2003). Several studies have compared the performance of different tracking solutions according to these parameters (Mobini et al.; Khoshelham et al, 2012; Clark et al, 2013). However, even though subjective considerations determine the VR experience, thus modulating the immersion and presence of the users (Weiss et al, 2006), limited research has focused on these aspects when using tracking systems. Interestingly, people with neurological impairments, as individuals post-stroke, who are one of the targets of the VR-based rehabilitation systems, may present sensory, motor, cognitive, and emotional impairments that can affect their interaction with the world (Kauhanen et al, 2000; Suenkeler et al, 2002), and consequently, their subjective perceptions when using tracking system.

The objective of this study was to evaluate the subjective perceptions elicited when using three different tracking technologies, optical, electromagnetic and skeleton tracking, in three different populations: healthy subjects, individuals post-stroke, and physical therapists.

2. METHODS

2.1 Participants

Three different groups of participants were recruited. The age of healthy subjects and individuals post-stroke was matched.

- *Healthy individuals.* The inclusion criteria in the healthy group were 1) age ≥ 55 and < 80; and 2) absence of previously reported motor or cognitive limitations. Individuals with previous experience with VR-based systems were excluded.

- *Subjects post-stroke.* The inclusion criteria in the stroke group were 1) age ≥ 55 years old and < 80 years old; 2) chronicity > 6 months; 3) absence of severe cognitive impairment as defined by Mini-mental state examination (Folstein et al, 1975) cut-off > 23; 4) able to follow instructions; 5) ability to maintain stride-standing position for 30 s without holding onto or assistance from another person as specified in the Brunel balance assessment, section 3, level 7 (Tyson et al, 2004); and 6) Berg balance scale (Berg et al, 1995) score ≥ 41. The exclusion criteria were 1) individuals with previous experience with VRHB systems; 2) individuals with severe dementia or aphasia; 3) individuals whose visual or hearing impairment did not allow the possibility of interaction with the system; 4) individuals with hemispatial neglect; and 5) individuals with ataxia or any other cerebellar symptom.

- *Physical therapists.* The inclusion criteria in the physical therapists group were 1) physical therapy degree; and 2) ≥ 2 years of experience in neurorehabilitation. Therapists with previous experience with VRHB systems were excluded.

2.2 Brief description of the tracking systems

Three different tracking solutions were used in this study: optical, electromagnetic, and skeleton tracking. The optical tracking consisted of two infrared cameras OptiTrack™ V100:R2 (NaturalPoint®, Corvallis) (Figure 1.a) aligned in the same plane. This setting allowed to locate spherical reflective markers present in the intersectional field of view of both cameras using epipolar geometry (Hartley et al, 2003).

A G4™ (Polhemus™, Colchester) was used as electromagnetic solution (Figure 1.b). Essentially, the tracking consists of an electromagnetic source and different sensors that are connected to a hub, which supplies them with power and transmits the tracking data to a PC. The sensors detect the electromagnetic field generated by the source and estimate their location and orientation (Raab et al, 1979).

With regards to the skeleton tracking, a Kinect™ and the Kinect for Windows SDK were used to track the body joints. This tracking solution estimates the depth information of the scene, detects the human silhouettes present in the depth images, and applies a statistical method to fit a skeleton in the silhouettes (Shotton et al, 2011).

(a) *(b)* *(c)*

Figure 1. *Tracking systems under study: (a) optical;(b) electromagnetic; and (c) skeleton tracking.*

A summary of the performance parameters of the tracking systems, principally defined by the manufacturer, is depicted in Table 1.

Table 1. *Characteristics of the tracking systems. *: Resolution, field of view, and wavelength are parameters of the optical tracking systems.*

Characteristic	**NaturalPoint® OptiTrack™ V100:R2**	**Polhemus™ G4™**	**Microsoft® Kinect™**
Measurements (cm)	Camera: 7.5x4.5x3.7 Marker: 4 (diameter)	Source: 10.2x10.2x10.2 Hub: 10.6x1.9x6.6 Sensor: 2.29x2.82x1.52	Camera: 7.5x4.5x3.7 (5.8x28.2x6.8 with the support base)
Weight (g)	Camera: 119.1 Marker: 8	Source: 725.7 Hub: 114.0 Sensor: 43.0	Camera: 590
Frequency (Hz)	100	120	30 (with 1 skeleton)
Latency (ms)	10	10 (in optimum conditions)	150-500 (Gieselmann, 2011)
**Resolution*	RGB: 640x480 (at 100 Hz) with 8 bits	-	RGB: 640x480 (at 30 Hz) with 8 bits Depth: 640x480 (at 30 Hz) with 11 bits
**Field of view (º)*	Horizontal: 46 Vertical: 35 (Default lens, 4.5mm F#1.6)	-	Horizontal: 57 Vertical: 43
**Wavelength (nm)*	850	-	850
Connections	Wireless	Sensor-Hub: Wired Hub-Source: Wireless (proprietary RF link at 2.4 GHz with frequency hopping architecture)	Wireless
Power supply	Camera: 5 V, 490 mA Marker: Passive	Source: 5 V, 1 A Hub: 5 V, 500 mA (rechargeable battery) Sensor: Passive	Camera: 12 V, 1.1 A
Cost ($)	1198 (including 2 cameras)	5250 (including 1 sensor)	249

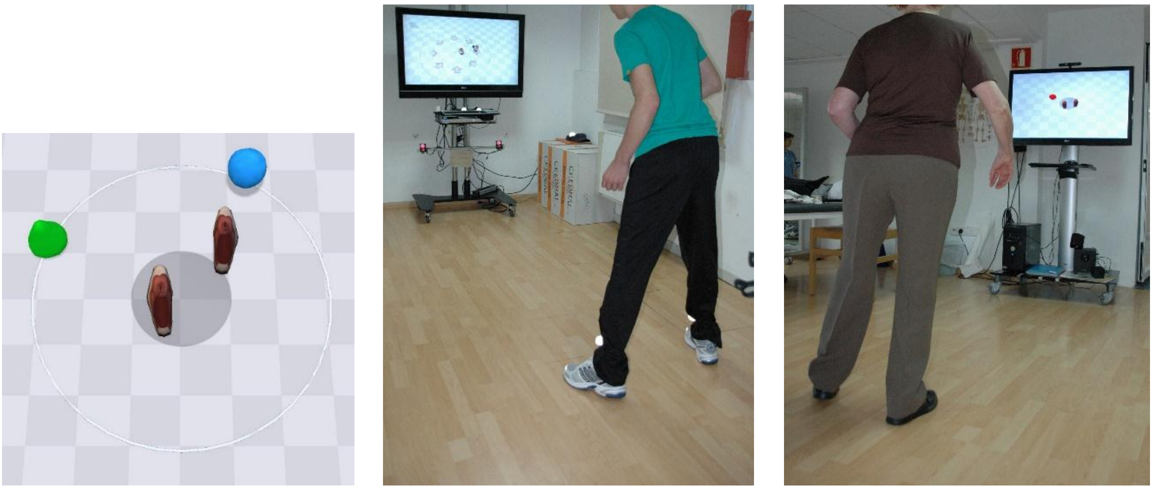
2.3 Virtual environment

A VR-based stepping exercise was used to assess the experiences of the participants of the three groups when using different tracking technologies. The VE consisted of an empty scenario consisting of a checkered floor whose center was indicated with a darkened circle. The participants were represented by two feet that mimicked the movements of their own feet in the real world with a third person perspective. Initially, both feet appeared in the center of the circle. Different items rose from the ground in the surroundings of the circle, and disappeared after a few seconds. The objective of the exercise was to step on the rising items with the nearer foot while maintaining the other foot (the support foot) within the boundaries of the circle. After stepping on the items, the leg had to be recruited towards the body and enter into the circle to allow stepping on the next item.

The ankle joints (tibiotalar) of the participants were located and transferred to the VE by the tracking systems. In the optical and electromagnetic solutions the joints were identified with reflective markers or electromagnetic sensors, respectively, fixed with a Velcro strip. The hardware setting of the VR system consisted of a standard PC, a 42" LCD screen, and one of the tracking systems described in the previous section.

2.4 Procedure

Three different VR units were installed in the physical therapy area of a neurorehabilitation center, each equipped with a different tracking system. The experiences of all the participants after using the three systems were collected through two ad-hoc questionnaires (A and B). Questionnaire A collected the experiences of healthy subjects and individuals post-stroke. Questionnaire B collected the experiences of physical therapists. The first four questions of both questionnaires evaluated the same topics.



(a) *(b)* *(c)*

Figure 2. *Virtual reality-based stepping exercise: (a) Snapshot of the virtual environment; (b) Participant interacting using the optical solution; (c) Participant interacting using the skeleton tracking solution.*

Participants belonging to the healthy and stroke group interacted with the stepping exercises in three 15-minute trials using the three tracking systems in counterbalanced order. The level of difficulty was determined by a physical therapist who supervised all the sessions, to define an attainable but challenging task. After each trial, participants filled questionnaire A. Questionnaire A consisted of six items that assessed 1) fixation speed of the sensors/markers, 2) ease of the calibration, 3) accuracy of the represented movements, 4) robustness, 5) comfort, and 6) order of preference. Responses to the first five items were rated on a 5-point Likert scale, where 1 means “very little/not at all” and 5 means “very much”. Responses to the last item were estimated as a percentage of preference.

The VR-based system was integrated in the physical therapy program. Patients who were attending a motor rehabilitation protocol in the neurorehabilitation center were assigned to train with the system according to their motor condition and expected benefits. Physical therapists monitored 45 training sessions with the VR-based exercise, 15 sessions with each tracking technology in randomized order. After the 45 sessions, the therapists, who were uninformed of the costs of the tracking systems during the entire study, were finally informed and filled in the questionnaire B for the optical, electromagnetic, and skeleton tracking. This questionnaire consisted of eleven items that assessed 1) fixation speed of the sensors/markers, 2) ease of the calibration, 3) accuracy, 4) robustness, 5) ease of fixation, 6) insensibility to changes in the clinical setting, 7) ease of assistance, 8) maintenance, 9) working range, 10) value for money, and 11) order of preference. As in questionnaire A, the first tenth items were rated on a 5-point Likert scale and responses to the last item were estimated as a percentage of preference.

2.5 Statistical analysis

Demographical comparisons among groups were performed with independent sample t-tests and Chi-squared or Fisher exact tests, as appropriate. Repeated measures analyses were performed using the non-parametric Friedman test ($\chi 2$, p values) to determine within-group differences between tracking systems (NaturalPoint® OptiTrack™, Polhemus™ G4™, and Microsoft® Kinect™). When the Friedman test yielded a significant effect ($p<0.05$), post hoc analysis was performed using a Wilcoxon signed-rank test for pairwise comparisons between tracking systems. The α level was set at 0.05 for all analyses. All analyses were computed with SPSS for Mac, version 20 (SPSS Inc., Chicago, USA).

3. RESULTS

After inclusion/exclusion criteria the healthy group consisted of 19 individuals (12 males and 7 females, 60.8±4.1 years old) and the stroke group consisted of 22 individuals (15 males and 7 females, 60.1±7.0 years old). The stroke group included ischemic (n=11) and haemorrhagic stroke (n=11), and presented a chronicity of 272.4±56.7 days. Of all the physical therapists working in the neurorehabilitation center, 14 therapists (6 males and 8 females, 31.8±2.4 years old) satisfied the criteria and accepted to be included in the study.

Table 2. *Scores of the subjective questionnaires. Only significant differences are stated. K=Microsoft® Kinect™, O=NaturalPoint® OptiTrack™, G4=Polhemus™ G4™. Friedman with Wilcoxon as post-hoc. *p<0.05, **p<0.001. Significance: > higher than, = same as.*

Issue	NaturalPoint® OptiTrack™	Polhemus™ G4™	Microsoft® Kinect™	Significance
Healthy, stroke individuals, and physical therapists				
A1/B1. Fixation speed of sensors/markers				
Healthy group	4.2±1.0	4.0±1.1	5.0±0.0	O=G , K**>O, K**>G
Stroke group	4.3±0.5	3.9±0.6	4.4±0.5	O*>G, O=K , K*>G
Professional group	3.6±0.8	3.2±0.7	5.0±0.0	O=G, K**>O, K**>G
A2/B2. Ease of calibration				
Healthy group	4.5±0.8	4.6±0.7	4.8±0.7	NS
Stroke group	4.3±0.6	4.4±0.5	3.0±0.6	O=G , O**>K, G**>K
Professional group	4.1±0.6	4.4±0.5	3.1±0.4	O=G , O**>K, G**>K
A3/B3. Accuracy				
Healthy group	4.7±0.5	3.7±0.9	4.3±0.8	O**>G, O*>K*, K*>G
Stroke group	4.2±0.7	3.9±0.8	3.4±0.7	O=G, O*>K, G*>K
Professional group	4.6±0.5	3.3±0.8	4.0±0.7	O**>G, O*>K, K*>G
A4/B4. Robustness				
Healthy group	4.5±0.6	4.7±0.4	4.0±0.8	G*>O, O=K, G**>K
Stroke group	3.9±0.7	4.3±0.7	3.4±0.7	G*>O, O*>K, G**>K
Professional group	4.0±0.8	4.6±0.5	3.3±0.8	G*>O, O*>K, G**>K
Healthy and stroke individuals				
A5. Comfort				
Healthy group	4.0±0.7	3.5±0.9	4.8±0.5	O*>G, K**>O, K**>G
Stroke group	4.0±0.5	3.3±0.6	4.7±0.5	O**>G, K**>O, K**>G
Professional group	-	-	-	-
Physical therapists				
B5. Ease of fixation				
Healthy group	-	-	-	-
Stroke group	-	-	-	-
Professional group	4.0±0.6	3.4±0.5	4.8±0.4	O*>G, K*>O, K**>G
B6. Insensibility to changes in the clinical setting				
Healthy group	-	-	-	-
Stroke group	-	-	-	-
Professional group	3.1± 0.6	3±0.8	3.7±0.5	O=G, K*>O, K*>G
B7. Ease of assistance				
Healthy group	-	-	-	-
Stroke group	-	-	-	-
Professional group	4.1±0.7	4.4±0.7	2.5±0.9	O**>K, G**>K, O=G
B8. Maintenance				
Healthy group	-	-	-	-
Stroke group	-	-	-	-
Professional group	4.4±0.7	3.3±0.9	4.9±0.3	O**>G, O=K, K**>G
B9. Working range				
Healthy group	-	-	-	-
Stroke group	-	-	-	-
Professional group	3.9±0.8	3.2±1.1	4.2±0.7	O*>G, O=K, K*>G
B10. Value for money				
Healthy group	-	-	-	-
Stroke group	-	-	-	-
Professional group	2.5±0.5	2.3±0.7	4.8±0.3	K**>O, K**>G, G=O
Healthy, stroke individuals, and physical therapists				
A6/B11. Preference (n, %)				
Healthy group	3 (15.8 %)	1 (5.2 %)	15 (79.0 %)	-
Stroke group	11 (50 %)	3 (13.6 %)	8 (36.4 %)	
Professional group	4 (28.6 %)	3 (21.4 %)	7 (50 %)	

Results of the three groups to the questionnaires showed that healthy subjects and physical therapists mainly preferred the skeleton tracking solution rather than the optical and electromagnetic solution (in that order). However, individuals post-stroke preferred the optical solution over the other options (Table 2).

4. DISCUSSION

Scores to the different items of the questionnaire are discussed below.

- *A1/B1. Fixation speed of sensors/markers.* All the groups reported the Kinect™ as the least time consuming system, followed by the optical and the electromagnetic solution. Despite the significant difference between the skeleton and the optical tracking reported by the healthy and professional group (0.8 and 1.4 in mean, respectively), individuals with stroke did not find this difference as relevant (0.1 in mean). The fixation speed of the electromagnetic sensors was reported to be the lowest by the three groups. Interestingly, the professionals evaluated it with the lowest score, which can be explained by the fact that they also had to be careful with the position of the wires to avoid tangles.
- *A2/B2. Ease of calibration.* No significant differences between tracking systems were reported by the healthy group. However, the stroke and professional group found the calibration for the skeleton tracking to be significantly more difficult than for the other systems ($p<0.001$), since it required the participants to move to be tracked. This fact made the task more difficult for individuals with stroke, who presented motor impairments, as reported by clinicians and themselves.
- *A3/B3. Accuracy.* The optical tracking system was reported to be the most accurate solution by all the groups ($p<0.05$), consistently with the results of the performance study. The same ranking order was found in the responses from healthy individuals and physical therapists. Individuals with stroke, however, reported the Kinect™ to provide the lowest accuracy ($p<0.05$). The presence of motor impairments could have led individuals with stroke to execute irregular movement patterns and postures that can affect the body parts recognition and skeleton fitting processes.
- *A4/B4. Robustness.* Similar conclusions can be inferred from the results of the robustness. All the groups defined the electromagnetic tracking solution as the most robust solution ($p<0.05$), followed the optical and the skeleton tracking system. Errors in the pose estimation could cause momentary maladjustments between the real and the virtual pose, which could be interpreted as a lack of robustness, especially by individuals with stroke and physical therapists, who reported the lowest scores (3.4 ± 0.7 and 3.3 ± 0.8, respectively).
- *A5. Comfort.* The skeleton tracking system, which did not require sensors, was evaluated as the most comfortable solution by healthy subjects and individuals post-stroke ($p<0.001$), followed by the optical and the electromagnetic solution. Differences between the optical and the electromagnetic tracking systems were also reported by the healthy ($p<0.05$) and stroke group ($p<0.001$). While the optical solution only required participants to wear reflective markers attached to their ankles, the electromagnetic solution also required them to wear a hub held to the waist of their pants, which was connected through wires to the sensors.
- *B5. Ease of fixation.* The professional group evaluated the skeleton tracking with the highest score, followed by the optical and the electromagnetic system (consistently with the scores in the fixation speed), which required therapists to fix the markers in the ankle joint of the patients. The electromagnetic solution, in addition, required the fixation of the hub and the careful placement of the wires in order to avoid tangles. The time and ease of fixation are crucial factors that must be minimized in clinical applications, where time is limited and should be dedicated to the physical therapy (Kwakkel, 2006; Han et al, 2013).
- *B6. Insensibility to changes in the clinical setting.* The therapists considered that the skeleton tracking system was the least susceptible system ($p<0.001$). However, the overall scores were low in comparison with other items. The optical solution was sometimes affected by reflections caused by chairs, room dividers, plinths, etc., elements commonly present in the clinical setting, or even by the sunlight. Even though these issues can be avoided by removing these elements of the field of view of the cameras or by closing the blinds, physical therapy units are dynamic areas where the spatial distribution is constantly changing and the sunlight is appreciated. The electromagnetic tracking system proved to be the most susceptible solution to the environmental changes.
- *B7. Ease of assistance.* The therapists reported that the electromagnetic tracking system was the solution that better allowed them to assist the patients. The physical principle of the G4™ made the performance of the system possible even when the therapists were between the source and the sensors. It allowed them to freely assist the patients from any position, and even to manipulate their extremities if needed. The optical tracking, on the contrary, required that the cameras had direct line-of-sight to the markers. The

assistance, although possible, had to be provided from behind. Similarly, the Kinect™ required direct line-of-sight with the participants' complete silhouettes. Since the statistical method to detect the body segments was trained with isolated human poses, when therapists were close to the patients, manipulating or touching them, the system was not able to fit a skeleton in the resulting silhouette. Therapists had to hide from the view of the Kinect™ in order not to affect the tracking, which derived in significant lower scores (2.5±0.9, $p<0.001$).

- *B8. Maintenance.* With regards to the maintenance, the therapists found that the need for recharging the hub of the electromagnetic tracking system after five to six hours of use was a limiting factor ($p<0.001$). The other tracking solutions did not required special maintenance.
- *B9. Working range.* The professional group reported that the skeleton tracking system provided the largest working area, followed by the optical tracking system and the electromagnetic solution, which had significant lower scores ($p<0.05$), consistently with the experimental results.
- *B10. Value for money.* The mass-produced Kinect™, which had the lowest price, achieved the highest score ($p<0.001$). Scores to the other tracking solutions were also consistent with their price.
- *A6/B11. Preference.* The healthy group mostly preferred the Microsoft® Kinect™ (79.0%), over the other tracking systems, which is consistent with their scores to the comfort item. Remarkably, this group did not experience significant problems when interacting with the system, as the Kinect™ is oriented towards healthy population. On the contrary, the stroke group mostly preferred the optical tracking system (68.2 %). The mentioned issues derived from a wrong skeleton fitting, more common in this group due to their motor restrictions, could have influenced their choice. These facts should be specially taken into account when working with individuals with stroke, since they are likely to present behavioural problems (Chemerinski et al, 2006), as irritability or depression, which can make this population particularly prone to frustration and reduce the benefits of rehabilitation (Flaster et al, 2013). In consequence, the use of the Kinect™ could be restricted to subjects with specific motor conditions. The therapists mostly preferred the skeleton tracking (57.1 %), slightly over the optical solution (35.7 %). This result could be explained as a trade-off between both systems. In spite the ease and speed of the Kinect™ startup and its ease of maintenance, the aforementioned issues with the Kinect™ can make the interaction of some patients difficult. The optical solution can overcome most of the interaction problems but it presents, however, some environmental restrictions (mainly light-related effects) that can affect their clinical use. An ideal situation allowing the use of these two tracking options, and the required space in the physical therapy unit, could satisfy all these requirements.

To summarize, our results show that subjective perceptions and preferences are from being constant among different populations, thus suggesting that these considerations, together with the performance parameters, should be also taken into account when designing a rehabilitation system. In general, the skeleton tracking system was preferred by therapists and healthy individuals, and by a great number of individuals post-stroke. With regards to the therapists, though the assistance with skeleton tracking system initially posed a challenge for them (reported as the main issue of the technology), once they knew its functional limits, they were able to provide assistance to the patients. This fact, together with its affordable cost, could have led them to finally adopt the skeleton tracking solution over the other systems, and can be the reason why they are using it currently in their daily practice.

Acknowledgements: The authors wish to particularly thank María Dolores Navarro and José Miguel Martínez for their help in this study. This study was funded in part by Ministerio de Educación y Ciencia Spain, Projects Consolider-C (SEJ2006-14301/PSIC), "CIBER of Physiopathology of Obesity and Nutrition, an initiative of ISCIII" and the Excellence Research Program PROMETEO (Generalitat Valenciana. Conselleria de Educación, 2008-157).

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Virtualising the nine hole peg test of finger dexterity

J Collins[1], S Hoermann[1,2], H Regenbrecht[1]

[1]Department of Information Science, University of Otago,
Dunedin, NEW ZEALAND

[2]Department of Medicine (DSM), University of Otago,
Dunedin, NEW ZEALAND

jonnymcollins@gmail.com, simon.hoermann@otago.ac.nz, holger.regenbrecht@otago.ac.nz

[1]*www.otago.ac.nz/informationscience*, [2]*www.otago.ac.nz/dsm-medicine,*

ABSTRACT

Using Virtual and Augmented Reality (VR/AR) approaches in physical rehabilitation can lead to better controlled, more client motivating, and more flexible forms of therapy. The Nine Hole Peg Test (NHPT) is a standard instrument in physiotherapy to practice and assess a patient's hand motor control abilities. A physical, wooden or plastic board with nine holes and cylindrical shaped pegs are used to perform this task. There are only limited ways of varying the degree of difficulty or to precisely measure progress with this physical setup. This study presents the development of a VR/AR version of the NHPT and evaluates the usability of three versions: (1) the real life wooden version, (2) a video-mediated version and (3) a computer-generated AR version built from low-cost off-the-shelf components. Our results show that all three conditions were successfully completed by all participants with the highest measured performance and perceived usability still achieved in the real life situation. This indicates that the implementation of currently available low-cost, off-the-shelf components is not yet reliable enough to suggest its use for therapeutic exercises or assessments that require very fine finger level interaction.

1. INTRODUCTION

Is a virtualised Nine Hole Peg Test as convincing in terms of usability, as a real version? This is the primary question investigated in this study. The Nine Hole Peg Test is a tool for the therapeutic assessment of finger function and is commonly used with people who suffer from impairments after stroke (Mathiowetz, Weber, Kashman and Volland, 1985). The purpose of a virtual version of the test is to allow a broader range of therapeutic applications as well as a more patient-based adaptation than the traditional test. For example, the difficulty could be adjusted based on the patients' performance and frustration tolerance as well as their motivation, this also allows patients with severe impairments to be treated who otherwise would not be able to perform the test.

The development of the virtual Nine Hole Peg Test (vNHPT) requires new hardware as well as software components. The general concept is based on Augmented Reflection Technology (ART) introduced by Regenbrecht et al. (2011) and used for a number of studies with healthy participants (Hoermann, Franz and Regenbrecht, 2012; Regenbrecht et al, 2012; Regenbrecht, McGregor, et al, 2011) as well as with clinical participants (Hoermann, Hale, Winser and Regenbrecht, 2012). For the specific implementation of the vNHPT however, more sophisticated tracking and rendering approaches are necessary.

In current rehabilitation, there are several approaches to help the patients gain back some of their motor functions. Among the most common is physiotherapy following the Bobath concept (Lennon, 2003), which often includes the use of external devices to support the patients in their execution of movement tasks. Another approach is Constraint-Induced Movement Therapy proposed by Taub, Uswatte and Pidikiti (1999). This involves restraining the healthy limb of the patient, and having them perform actions with their impaired limb. Doing so for extensive periods of time (i.e. up to 90% of waking hours) has been shown to improve motor deficits of patients suffering from impairments after stroke (Miltner, Bauder, Sommer, Dettmers and Taub, 1999).

A less restraining approach is one which takes advantage of the manipulability of human perceptions, beliefs and even sensations. It was in fact shown that psychotherapies such as Cognitive Behaviour Therapy, involving

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only talking, have effects on the brain (Straube, Glauer, Dilger, Mentzel and Miltner, 2006). Similar changes in the brain were also shown in a stroke patient treated with Mirror Visual Illusions (Michielsen et al, 2011).

This phenomenon is commonly referred to as “neuroplasticity” and is described as the brain’s ability “to respond to intrinsic and extrinsic stimuli by reorganizing its structure, function and connections” (Cramer et al, 2010). In order to make best use of it, therapy approaches should focus on providing environments that allow meaningful therapeutic movements, with adequate intensity and repetitions, as well as motivating the patient and providing appropriate feedback (Holden, 2005). Virtual and Augmented Reality Environments have the potential to be used in this context.

In this paper an implementation of such an environment is presented and compared with its real life counterparts.

2. SYSTEM

There are three main technical components and the physical apparatus itself that contribute to the system. (1) An off-the-shelf webcam with a built in 3D depth sensor with a resolution of 320x240, and an HD 720p RGB image sensor (Interactive Gesture Camera, Creative Technology Ltd) mounted on a custom build frame (Fig. 2), (2) a tailor-made plugin to process the data from the webcam for delivery to the application, and finally (3) a virtual reality application created using the Unity3D game engine (version 4.2, unity3d.com) which provides the final environment in which the users perform their tasks in.

The webcam’s functions are accessed from the plugin using the Intel Perceptual Computing SDK 2013 (software.intel.com/en-us/vcsource/tools/perceptual-computing-sdk). This provides access to the raw data from both the depth and the colour sensors and provides features such as basic finger tracking.

The hardware “therapy frame” (Figure 1 left) where the webcam is mounted, consists of a flat board with a metallic frame attached to the front of it. On the top of the frame, the webcam (described above) is attached and points toward the board at a 45 degree angle. A black curtain in front of the frame prevents the user from seeing the real interaction (Figure 1 right). This is to direct the participants’ attention to the interaction shown on the screen and to maintain the illusion of interacting in the virtual space during the tasks. A blue fabric is used to cover the base.

Figure 1. *Metal Frame used to position the depth cam without curtain (left) and with the curtain to prevent the direct view of the hand during use (right).*

2.1 Finger Tracking

The target action required for task completion in this study is a grabbing action where the participant grabs a peg and places it in the board using the index finger and the thumb (Figure 2). For this, only two coordinates need to be tracked which are the x, y and z coordinates of the thumb and index finger. First the blue background (the fabric covering the table) is being subtracted from the video image leaving only the pixels representing the hand. The colour blue is used because in the (HSV) colour space, blue is the closest opposite to the average skin colour. Then we traverse the remaining image (which is now containing only the hand), starting with the top left pixel moving right, and then down until finding an opaque pixel (not made transparent by the background subtraction method). With this, the first fingertip is found, then by ignoring all pixels below the initial point found, and either side for a threshold of 45 pixels, resuming the search will result in finding the second fingertip.

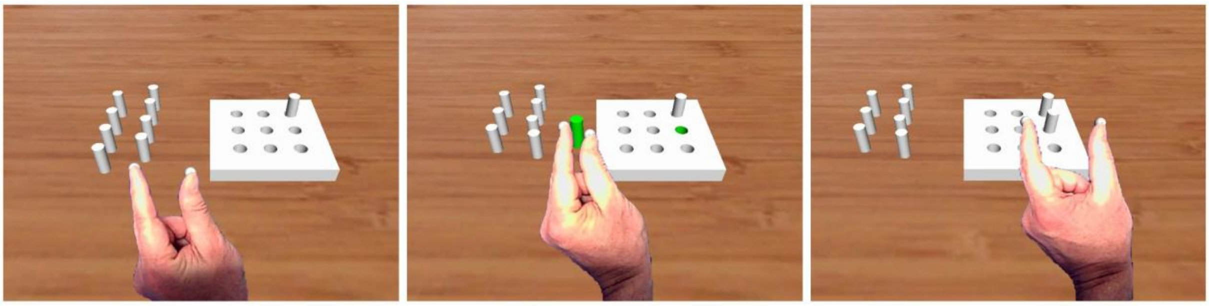

Figure 2. *Reaching for a virtual peg (left), moving it towards its destination (centre) and releasing it (right).*

The coordinates of these two points are stored and their depth values are retrieved using the Intel SDK. The Unity3D plugin uses these computed coordinates to control the interaction with the virtual environment.

2.2 Virtual Environment

The graphic engine Unity3D was used to create and display the environment and handle the interactions with the objects in this environment. Within Unity3D, C# scripts were programmed which retrieve the coordinates of the fingers and import the video image of the hand into the virtual scene from the plugin. For each frame, the plugin function is called and copies the image data of the users hand as a texture to a virtual plane, and at the same time the two 3D coordinates of the finger and thumb are retrieved. Since the blue background of the hand images was removed the user gets the impression of seeing the own hand in the virtual environment.

The virtual NHPT model in Figure 2 was created in Google Sketchup Make (version 13). This model was exported as a Collada model and then imported directly into Unity3D. The way we use the fingertip data to interact with the peg models is by checking three conditions. First we find the midpoint between the two fingertips, and we cast a virtual, invisible ray through that point and check if that ray collides with any peg. If it does, we then calculate the Euclidean distance between the two fingertips, and if the distance is small enough (to represent the grabbing gesture), then the third check is performed which is testing if the depth coordinate of the two fingertips is equal to that of the peg which the ray is colliding with. When all three of these conditions are satisfied, the peg will attach itself to the midpoint and will move with the fingertips. Placing the peg in the hole of the virtual board utilises a sphere collider (invisible/un-rendered) placed in each hole, and if the peg that was being moved collided with the sphere collider in the appropriate hole then the peg releases itself in that hole.

In order to prevent the pegs from being moved outside of the visible area, a condition was added that limits the working environment and if this condition is violated the peg that violates this condition is returned back to its initial starting position.

3. METHOD

The virtualized Nine Hole Peg Test (vNHPT) was implemented and compared to the original wooden Nine Hole Peg Test (NHPT). In three experimental conditions the vNHPT was compared to two conditions of the traditional NHPT: (1) the original NHPT performed with direct vision, and (2) the NHPT mediated through the webcam and computer system but using the original wooden components.

3.1 Participants

Eighteen participants were recruited from the University of Otago. The sample consisted of 9 male and 9 female students from a range of disciplines, and between the ages of 18 and 25 years. All participants provided written informed consent and received a $10 grocery voucher as compensation for their time.

3.2 Measures

The traditional Nine-Hole Peg Test (NHPT) kit used for comparison was made from a piece of wooden board and has nine holes drilled in it evenly spread apart. The nine pegs were cut to equal length from a piece of wooden dowel. The test kit was made according to the standard described in Mathiowetz et al. (1985).

There were two questionnaires involved in this experiment, a demographics and a usability questionnaire. The demographics questionnaire was first given to the participants requiring information such as age, gender, handedness, possible vision impairments, physical well-being, previous augmented reality experiences, and previous involvements in similar experiments. After completing the tasks the usability questionnaire was presented evaluating their experience with the system. This questionnaire was divided into three sections to be filled out after each condition.

The usability questionnaire was composed of questions from the Mixed Reality Experience Questionnaire (Regenbrecht et al, 2013). Some questions were modified slightly as to fit the nature of the experiment. The questionnaire can be divided into two main parts. There were 13 questions in total, nine of which can be categorized as direct usability assessment of the condition, and 4 of which are assessing the environment surrounding the condition. There were five questions to assess the task of physically reaching, grabbing, moving, placing and releasing the pegs when performing the test. Each of the questions were measured on a Likert scale (1 – 7) with 1 being "strongly disagree" and 7 being "strongly agree". As well as having a questionnaire to evaluate user performance, each condition was timed using a stopwatch to measure the completion time.

3.3 Design

The experiment uses a within-subject design with the 18 participants pre-randomised and counterbalanced across the three conditions. The independent variable consists of the three conditions of the NHPT, and the dependent variables are time to complete the task, user satisfaction, and perceived performance.

3.4 Procedure

Experiments were run in a controlled lab environment (Computer-Mediated Realities Lab) to reduce unnecessary distraction for the participants. In total three conditions were evaluated: real life (RL), video mediated (ME), and augmented reality (AR) versions of the NHPT.

Upon their arrival participants were greeted and given an information sheet detailing the experiment and what they should expect. After reading this, they were presented with a consent form to give their formal consent. They were then shown their first condition and timed with a stopwatch. After each condition participants had to complete the usability questionnaire regarding their experience. Participants repeated this procedure for all three conditions.

In the RL condition, the wooden board was placed on a table in front of the participant (see Figure 3 (left)) and the users were instructed to use their left hand to transfer the pegs one by one to the holes. In contrast to the original NHPT, the holes on the board were numbered in the order in which the participants were to move the pegs to. The reason for this was to keep the tasks as similar as possible for each condition and in this case slightly adapt the real world NHPT procedure to the virtualised version. When the user picked up a peg, a hole would light up (green) on the board to show which hole to place the peg in.

Another small modification from the original NHPT protocol, again to retain tasks as similar as possible between conditions, was that the pegs starting position was standing upright in a second real board. This board replaced the box where the pegs would be lying in the original version of the test and the users are meant to grab the pegs from that box. Pegs in both the virtual and the real space were constrained to an upright starting position.

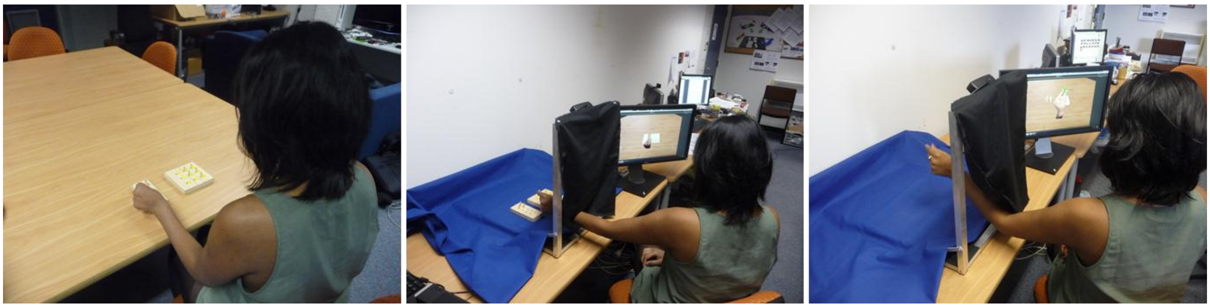

Figure 3. *Photos of a participant exercising in the three conditions: real life RL (left), video mediated ME (centre) and virtual VR (right).*

The Video-Mediated (ME) condition involved having the real NHPT placed in the exact same manner within the apparatus as the virtual one (see Fig. 3 centre). The participants were instructed to complete the test by moving the pegs from the initial board to the final peg board one by one, again using their left hand, except for this condition they are allowed to move the pegs to any hole they choose. This was because it was too difficult to see the number labels on the peg board, and it was decided that it was less confounding than to ask the participant to remember the order of the holes. In this condition the user were allowed to observe only the scene on the monitor, see Fig. 4 (left), while the NHPT was hidden from their direct view.

The AR condition, see Fig. 3 (right) had again the participant sitting at the apparatus and referring only to the scene shown on the monitor. The task was the same as in the other conditions; participants had to place all pegs one by one into the board. When a peg was grabbed, the peg turned green, and a hole lit up to indicate where to place the peg see Fig. 4 (right). Before users were to complete the AR condition, they were shown the environment, and given a small time to navigate the space and interact with 3 virtual pegs. This was to accustom the user to the new environment and reduce a possible so called “wow-effect” with new technologies.

After completion of the third and final condition and after filling in the usability questionnaire, participants were thanked, compensated with the grocery voucher and released.

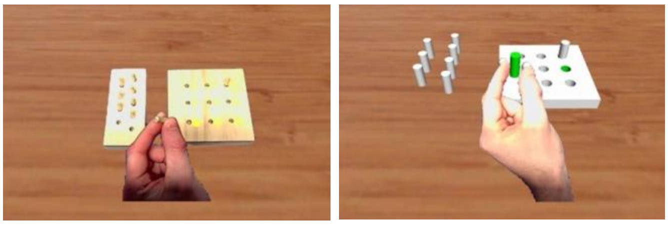

Figure 4. *Monitor screenshots of ME (left) and AR (right).*

3.5 Statistical Analysis

Data analysis was carried out in SPSS version 21. A 95% confidence interval was used. First the questionnaire data was checked for normal distribution using the Shapiro-Wilk method. This test returned a significant result for the real life condition ($p < .001$), but not for the video mediated and virtual conditions of ($p = .875$, $p = .970$), showing the real life condition is not normally distributed. This was expected because almost all of the questions were designed to cater for all three conditions. The distribution of the values in the real life condition showed that they were very lopsided with a large majority of usability questionnaire answers resulting in an answer of 7. Following this, non-parametric tests needed to be applied on the data. First a Related-Samples Friedman’s Two-Way Analysis of Variance by Ranks was applied across all questions for each condition. If significance was found, Related-Samples Wilcoxon Signed Rank test was applied to the data to determine if the differences between conditions were significant. The analysis of bivariate correlations used one-tailed Kendall’s tau-b correlations coefficient. The ratings for Q13, “I had the impression of seeing the pegs as merely a flat image”, were inverted prior to the data analysis to align it with the other questions.

4. RESULTS

4.1 Overall Combined Scores

As expected the RL condition returned the highest values with $M = 6.69$ ($SD = 0.368$, $IQR = 7–7$). The ME condition closely followed with ($M = 5.01$, $SD = 1.023$, $IQR = 4–6$). Questions for the AR condition returned lower values with ($M = 3.88$, $SD = 0.824$, $IQR = 3–5$). The non-parametric tests applied to this data showed significant differences ($\chi^2 = 2$, $p < .001$).

4.2 Task

Similar to the overall questionnaire results, RL returned the highest values for the nine questions regarding the task itself with values of $M = 6.70$ ($SD = 0.393$, $IQR = 7–7$). The ME and AR returned values of ($M = 5.18$, $SD = 0.954$, $IQR = 4–6$) and ($M = 3.89$, $SD = 1.01$, $IQR = 3–5$) respectively. When the non-parametric test is applied to the task questions we receive results of ($\chi^2 = 2$, $p < .001$). Again a strong significance value is found which supports a large difference in the performance of each task.

4.3 Environment

The four questions regarding the participants’ perception of the environment returned results in the same order with RL > ME > AR (RL: $M = 6.68$, $SD = 0.451$ $IQR = 6–7$; ME: $M = 4.73$, $SD = 1.40$, $IQR = 3–6$; AR: $M = 3.88$, $SD = 0.710$, $IQR = 3–5$) respectively. Non-parametric results give ($\chi^2 = 2$, p < .001). When using Related-Samples Wilcoxon Signed Rank Test to compare each of the conditions, there was significance found between all of the conditions with both RL-ME and RL-AR giving values of ($p < .001$). There was however less significance found between the ME and AR condition as the graph in Figure 6 suggests with a value of ($p = .015$).

4.4 Single Question Comparison

The results for each individual question of the three conditions are shown in Table 1. It shows that in the AR condition, participants rated Q1, Q2, Q6, Q8, Q9, and Q10 significantly below ($p < .05$) the neutral midpoint at level "4". In contrast Q3, Q12 and Q13 were rated significantly positive by the participants. This could indicate that they did not have any negative experiences in these parts.

Table 1. *Results of questionnaire (results significantly above neutral midpoint are highlighted in green and results significantly below in red).*

	RL			ME			AR		
	Mean	*SD*	*IQR*	*Mean*	*SD*	*IQR*	*Mean*	*SD*	*IQR*
Q1–It was easy for me to reach the pegs	6.89	0.32	7–7	5.78	1.06	5–6.25	3.17	1.47	2–5
Q2–It was easy for me to grab the pegs	6.83	0.38	7–7	6.00	0.97	5.75–7	2.83	1.38	2–4
Q3 –It was easy for me to move the pegs	6.94	0.24	7–7	6.06	1.00	6–7	5.17	1.54	3.75–6
Q4–It was easy for me to place the pegs in the board	6.44	0.78	6–7	3.78	1.26	3–5	4.39	1.42	3–5.25
Q5–It was easy for me to release the pegs	6.83	0.38	7–7	6.22	0.81	5.75–7	4.94	1.51	3.75–6
Q6–It was easy to perform the task overall	6.72	0.57	6.75–7	4.61	1.46	3–6	3.17	1.15	2.75–4
Q7– I could complete the task to my satisfaction	6.72	0.57	6.75–7	4.78	1.83	3.5–6.25	4.17	1.54	3–6
Q8–I was fast in completing the task	6.22	0.94	5.75–7	4.22	1.56	3–5	3.28	1.36	2–4
Q9–I had the impression I could grab the pegs at any time	6.89	0.32	7–7	5.06	1.47	3.75–6	3.22	1.52	2–5
Q10–The handling of the pegs felt natural to me	6.50	0.86	6–7	5.00	1.71	3.75–6.25	2.61	1.14	2–4
Q11–I could tell where the pegs were positioned in space	6.72	0.46	6–7	4.44	1.72	2.75–6	3.50	1.50	3–5
Q12– I had the impression of seeing the pegs as 3D objects	6.67	0.77	6.75–7	4.67	2.17	2–6.25	5.06	0.87	4.75–6
Q13–I had the impression of seeing the pegs as merely a flat image*	6.61	0.78	6–7	4.50	1.72	2.75–6	5.00	1.08	2–5

** inverted values*

4.5 Comparison of Times

The completion times were checked for normality using the Kolmogorov-Smirnov test with both the RL and ME conditions sitting within a normal distribution with values of (p = .157) and (p = .066) respectively, however the AR condition resulted outside of normal distribution with a significance value of (p = .002).

Given that one condition was outside of normal distribution, we used Related-Samples Friedman's Two-Way Analysis of Variance by Ranks to analyse the data. This returned values of ($\chi^2 = 2$, $p < .001$) showing significant difference between conditions. The AR condition returned the highest values with (M = 167.94, SD = 116.73) followed by the ME task with values of (M = 48.34, SD = 19.28) and finally the lowest values in the RL condition with (M = 13.55, SD = 2.3) (all significant with $p < .001$).

4.6 Correlations between conditions

The analysis of correlation between the more similar conditions showed a tendency with a positive correlation of the time used between the RL and the ME condition τ=.262, p = .065 and the ME condition to the VR condition τ=.255, p = .07. The correlation between RL and VR was not significant τ=.170, p = .162.

5. DISCUSSION AND CONCLUSIONS

In this study we demonstrated that the NHPT can be virtualised, although it is not yet as convincing as the real world test in terms of usability. The results show significant differences between each of the conditions. Participants found the RL condition easier than performing the ME condition. This could be due to the positioning of the camera and screen (see Fig. 3) as well as the fact that users see a 2D version of their own hand performing the test. This could have made it hard for them to see the holes on the board. Furthermore, when the users perform the RL scenario, they have the test directly in front of them, whereas the viewing angle (due to the position of the monitor) could contribute to further disorientation/difficulties when completing the ME and VR conditions. It was observed that users would face their body towards the monitor and perform the actions holding their arm out to the left (see Fig. 3). When comparing the users' view of the ME and VR scenarios (see Fig. 4), there is a slight difference between the perspectives. The boards appear to be at different angles which could also be contributing to users' difficulties due to inaccurate depth perception.

When performing the virtual version of the test, it was observed that when participants tried to move their arm in depth to reach the pegs, they would move horizontally forward in real space. Due to the angle of the camera relative to the table top, the depth sensor does not sense the users' forward action as purely moving away from the user. This causes the virtual "fingertip spheres" to move within the environment in a perceptually incorrect way. For example, the spheres will not move in as much depth in the virtual space as the user is moving in real life. For this reason, some participants had difficulties picking up pegs and placing them. Results showed that users found placing the peg on the board much easier than grabbing the peg. Furthermore, the camera used is developer hardware and software which meant that in this case, the data retrieved from the SDK was somewhat unreliable. To the participants it was noticeable in the AR condition when the depth camera temporarily faulted, because if a depth coordinate was not supplied, then some default value was used. Unfortunately, this just made the peg move back to its starting location.

The time required to complete the conditions showed that there was a large variance between participants when they used the vNHPT. The real life NHPT was significantly easier to perform than the vNHPT. There is evidence though that not all parts of the vNHPT conditions contributed equally to this difference. This was shown by the results of the ME condition which were not significantly different from the vNHPT condition in terms of the environmental perception questions. In fact the mean values of the environment questions in the ME condition were only slightly higher than in the AR condition. Therefore the display and execution of the task by just observing the screen seemed to possibly have negatively influenced the performance of the participants. This should be addressed in future research by optimizing the display condition.

The results from the questionnaire suggested various areas of possible future improvements of the virtualised condition. Apart from the task of placing the peg in the virtual board, most tasks were identified to be significantly harder compared to the other conditions, notably the RL condition. It was easier for participants to place the pegs in the virtual board than it was to place them in the board in the ME condition. The question that gave the lowest response was the more general question about the handling of the pegs and whether it felt natural to the user. There were some positive aspects such as the task of moving the pegs from one location to another. This was expected given that the peg attaches itself to the midpoint between the fingertip spheres once the conditions for picking up the peg are satisfied. The 3D aspect of the condition was also identified easily by users.

It is important to note that a possible limitation of such an implementation is the obvious lack of haptic feedback within the augmented environment. With question 10 "The handling of the pegs felt natural to me" gaining the lowest score with regards to the AR condition, it is likely that the aforementioned limitation of not being able to feel the peg had an effect on the results of this question. Either directly or indirectly, this is could also have affected the users' performance in the AR environment.

The hardware setup for this research placed the users' monitor off to the side next to the camera-frame, tracking the users' hand. This meant that the participants were looking in a different direction to where the action was occurring, which could potentially have affected the users' feeling of presence, comfort, and performance. This could be overcome by using a hardware setup similar to the ART system (Regenbrecht et al. 2011) which places the monitor directly in front of the user and therefore helps the users have the experience as if they are looking at their hands more directly.

There is also considerable potential for improvements to be made at the technical and implementation levels of the virtualisation of the NHPT. As stated above, the depth information retrieved through the Intel SDK was somewhat unreliable. Also, the finger tracking module could be improved, e.g. by making better use of the depth information in conjunction with the colour image. The difficulty here is that the colour image provided by the SDK is not only of a higher resolution (1280 X 720) than the depth image resolution (320 X 240) but they are even different in their aspect ratios. There are various other tracking methods available which could potentially provide more reliable tracking data, however, most of these devices or methods require the users' hand(s) to have an instrument attached in some way (i.e. data gloves). The idea of our rehabilitation scenario is that it provides the users with a natural interface so to facilitate the users' feeling of presence in the environment. Data gloves could provide a reliable stream of data but then the user is "wired" to the computer. An advantage of having an un-instrumented system as presented here is that users are able to observe their "real" hands in the virtual environment, which potentially facilitates the users' presence in the augmented environments.

As a virtual environment is adaptive in nature, this could be utilised to modify the NHPT for different users. For example, the board and pegs could be made bigger to make picking them up and placing them much easier for a user with less mobility and motor control. It would also be possible to scale movement so that it appears that they are moving the peg further than they are really moving their arm. Different tasks could be implemented such as changing the order of the holes which the pegs should be placed in, or increasing and decreasing the number of holes. These are just examples of adaptations which can be made to the vNHPT application.

Time and distance measures can also be put in place in the application which can accurately record both completion time, and distances. These kinds of data can be analysed further by physiotherapists and used for motivation of patients. It is also possible to record the task being completed so it can be further observed and analysed.

Hybrid approaches can also be implemented with the possibility of using for example the real NHPT board but virtual pegs. The camera approach also comes with its flaws, most of which are of a technological nature. The Intel development software is still flawed and is still being updated. The background subtraction could also be improved as the current version is compromised if there is too much natural sun light on the apparatus.

Acknowledgements: We would like to thank the participants for taking part in this study as well as the staff who helped us. Thanks also to the Department of Information Science for funding the research. Thanks to Patrick Ruprecht for his input and technical support. This study was part of the thesis work of the first author, supervised by the last author. This study was approved by the University of Otago Ethics Committee.

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Development of a new scoring system for bilateral upper limb function and performance in children with cerebral palsy using the MIRA interactive video games and the Kinect sensor

I M Moldovan[1], A D Călin[2], A C Cantea[2], L A Dascălu[2], C A Mihaiu[2], O Ghircău[1], S Onac[1], O Rîză[1], R A Moldovan[3], L V Pop[4]

[1]Socio-medical services complex “Maria Beatrice”, Alba-Iulia, ROMANIA

[2]MIRA REHAB LIMITED, London, UK

[3]Alba-Iulia Emergency County Hospital, ROMANIA

[4]“Iuliu Hațieganu” University of Medicine and Pharmacy, Cluj-Napoca, ROMANIA

[1]*ongmariabeatrice@yahoo.com*, [2]*contact@mirarehab.com*

[1]*www.mariabeatrice.ro,* [2]*www.mirarehab.com*

ABSTRACT

The aim of the study is to develop a reliable and valid occupational therapy scoring system for the assessment of bilateral upper limb function and performance in children with cerebral palsy (CP) using adapted MIRA (Medical Interactive Rehabilitation Assistant) interactive video games and the Kinect 360 Xbox sensor. MIRA is a software platform that uses the Kinect 360 motion sensor to interact with several video games adapted for children with cerebral palsy. 16 healthy children and 11 children diagnosed with cerebral palsy played four MIRA games that generate three performance quantifiers: distance (m), average acceleration (m/s^2) and score (points). The reliability and the validity tests performed suggest that the scoring of the MIRA testing schedule is a reliable and valid occupational therapy tool for the assessment of bilateral upper limb function and performance in children with cerebral palsy.

1. INTRODUCTION

Cerebral palsy (CP) is a neurologic impairment that starts at birth and leads to variable degrees of disability throughout the entire lifespan. It is the most common cause of physical disability in children (Rosenbaum, 2003) with a rate of 2 to 2.5 per 1,000 live births (Stanley et al, 2000).

Assessing motor function in children with cerebral palsy is a difficult task since many forms are encountered in clinical practice (hemiplegia, tetraplegia, diplegia, ataxia, and dyskinesia). The Gross motor function classification system (GMFCS) is a widely internationally-adopted scale that describes the self-initiated movements with particular emphasis on the control of the trunk and lower limbs (Palisano et al, 1997). The five-level scale is based on the concepts of disability (World Health Organization 1980) and of functional limitation (National Institutes of Health 1993). The Manual Ability Classification System (MACS) was designed to evaluate how children with CP use their hands when manipulating objects in daily activities (Eliasson et al, 2006). It is a five-level scale focused on manual ability, as defined in the International Classification of Functioning, Disability and Health (ICF; World Health Organization 2001). There is a lack of correlation between the upper limb and lower limb abilities in children with cerebral palsy. An exact agreement between MACS and GMFCS levels was found only in half of the children, suggesting that rehabilitation programs for the upper and lower limbs should be judged separately (Eliasson et al, 2006).

There is a growing interest in recent studies for developing new therapeutic interventions in order to increase the movements of the arms and hands of the children with CP (Mayston, 2001). However, MACS has a low sensitivity in identifying small changes in the arms and hands function. Thus, several occupational therapy assessments were developed. In order to demonstrate that a new therapeutic method is efficient, it should generate a significantly statistic improvement on a valid and a reliable scale. Without valid and reliable scales it is impossible to test the efficacy of a new therapeutic method. For children with bilateral upper limb neurologic impairments aged 5 to 15 years, the Melbourne Assessment of Unilateral Upper Limb Function (MUUL) is the

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most appropriate test (Wagner et al, 2012). It consists of videotaped occupational therapy sessions followed by an interpretation session in which the therapist quantifies the performance. The average time for evaluation of one upper limb is one hour, so for the bilateral evaluation of both upper limbs it reaches up to two hours.

Movement-based interactive video games (IVG) using Nintendo's Wii® and Microsoft's Kinect® motion sensors is a promising new therapy for children with cerebral palsy. The method is very well accepted by children, and seems to be effective in improving arm motor control, functional status, activities of daily living (ADL) and balance (Winkels et al, 2013; Tarakci et al, 2013; Gordon et al, 2012).

Interactive video games using Kinect 360 Xbox sensor of motion provide much information regarding parameters of movements (speed, acceleration, distance) that can be used in the evaluation of the upper limb function. Certain tasks can now be transferred from occupational therapy sessions into virtual occupational therapy sessions making the activity entertaining, motivational and fun. The instant scoring offered by the game can quantify the performance in achieving tasks thus reducing the time needed for the evaluation consisting in videotaped occupational therapy sessions.

The aim of the study is to test the reliability and the validity of the MIRA testing schedule, a set of four different movement based MIRA games designed to evaluate the upper limb function and performance in children with neurological impairments.

2. METHODS

2.1 Participants

11 children (4 girls and 7 boys), aged 4 to 11 years, diagnosed with cerebral palsy, included in "Maria Beatrice" Rehabilitation Center, Alba-Iulia, Romania, played the MIRA interactive video games using the Microsoft Kinect 360 Xbox sensor. 16 healthy children (10 girls and 6 boys), aged 4 to 10 years, included in the control group, also played the same interactive video games.

2.2 Interactive video games

MIRA (Medical Interactive Rehabilitation Assistant) is a software platform that uses the Kinect sensor to interact with medical video games created specifically as an aid for physical rehabilitation therapies and diagnosis. MIRA's therapeutic efficacy in rehabilitation is currently under investigation. The platform provides a patient management application designed for physiotherapists to store patient data related to their condition and diagnosis, create personalised therapy sessions and visualize statistics about their improvement. Thus, a dedicated rehabilitation schedule can be created for each patient from the medical games contained by the platform and it can be designed to test, train and measure several types of movements, in order to improve and quantify the range of motion, the coordination and the patient engagement.

The sensor used by MIRA, Microsoft Kinect, comprises an RGB video camera and two monochrome Infra-Red (IR) sensors of which one is also an IR laser projector, based on which a 3D depth map is created. The Kinect sensor allows recognition of the 3D location of the body joints, thus permitting the MIRA platform to analyse the movement and offer important feedback containing statistics and measurements. The joints/limbs that can be tracked are: head, shoulder centre/right/left, elbow left/right, wrist left/right, hand left/right, spine, hip centre/left/right, knee left/right, ankle left/right, foot left/right.

This study is focused on the use of the upper-limb MIRA package, mainly on games created for the rehabilitation in neurologic conditions of children. It combines physical, occupational and recreational therapies that are commonly used for the rehabilitation of the children with cerebral palsy. The movement-based interactive video games are created to target goals pursued in the traditional rehabilitation therapies: to develop coordination, maintain and improve flexibility and function in every-day activities, overcame physical limitation, increase self-confidence and induce positive emotions to encourage cooperation and perseverance. The games used in this study are Catch, Follow, Move and Grab, each having three difficulty levels (easy, medium and hard) and a series of levels that progress gradually. The data obtained from the Kinect sensor are processed and scaled according to the dimensions of the user's arm, such that, after calibration, the shoulders are mapped to the center of the screen and the user is able to reach with his or her hand a position mapped on the margins of the game's margins only when he or she stretches their arm completely, without moving their body.

2.2.1 Catch. Catch is a game that requires the user to move the arm in order to catch several objects appearing on the screen, in which case they receive points. If objects were not caught in a specific amount of time, they disappear and others will replace them in several locations of the screen. As the difficulty increases, the objects remain on the screen for a shorter time. In the hard level, the objects are in movement. High velocity and high acceleration movements are required for the completion of this game.

2.2.2 Follow. In Follow the user has to keep the hand on a shape on the screen and follow it as it moves around the screen on random path. While the users keep their hand on the shape, they gather points and a song will be playing. When their hand is not on the shape, the volume of the song decreases until it stops. The sound reappears when the hand positioning is correct. As difficulty increases, the time allowed for the hand to be outside the shape shortens and the speed of the moving shape increases. High precision movements of the arm are required to complete this game.

2.2.3 Move. The game Move requires the user to move objects with their hand on a predefined path. Paths come out in the order of their difficulty: verticals, horizontals, diagonals, and then circles and waves. Some points are given when the item is picked up, but most of them are rewarded when the objects reached the final position of the path. Getting out of the path for a certain amount of time implies losing the object (and some points) and starting all over again from the beginning of the path. As difficulty increases, the buffer time when the user is allowed to be off paths is shorter. This game requires movements that resemble the coordination tests used in the cerebellum dysmetria tests.

2.2.4 Grab. Grab is the only game that requires the use of two hands to pick up an object from a shelf and place it with both hands on the upper shelf. Moving hands too far away from each other might result in dropping the object, which must be picked up again, and in losing some points. Some points are given when picking up objects and most of the points come when the object is placed on the specified location on the shelf (Figure 1). As the difficulty increases, the upper shelf is moved higher and higher, and the distance allowed between the hands without dropping the object is smaller. The movements required are well coordinated, similar to those used in activities of daily living.

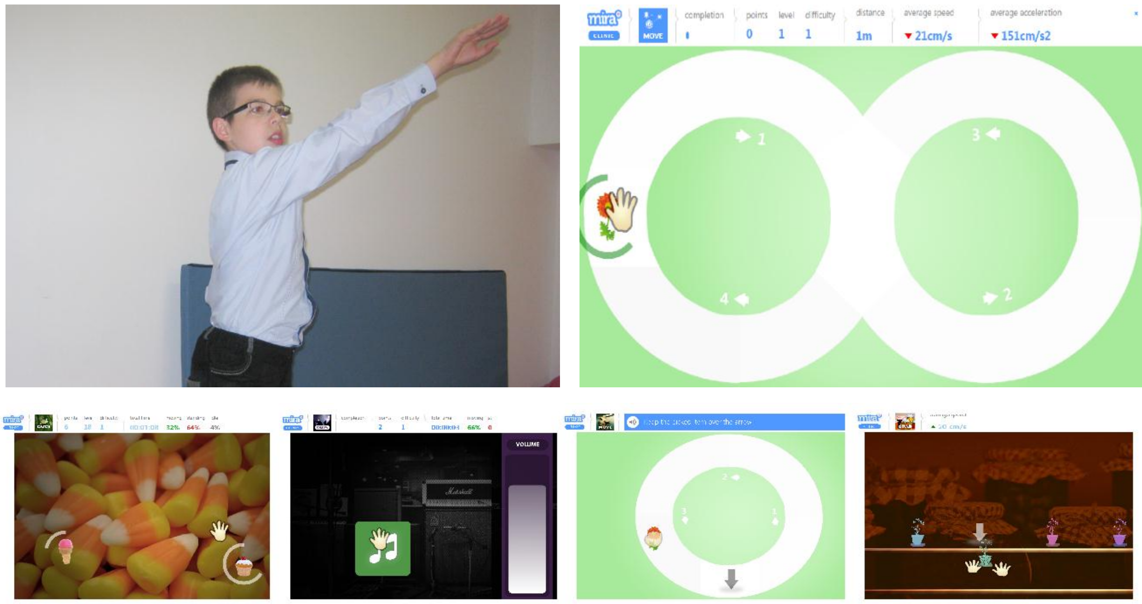

Figure 1. *Snapshots of the MIRA video-games; in order: a child with cerebral palsy while playing, Move - infinite path, Catch, Follow, Move - circle path and Grab. A short movie of MIRA testing schedule is available at http://www.mariabeatrice.ro/mira/mira-testing-schedule.*

During gameplay, the platform gathers movement statistics for each hand used in the games: time played, moving (active) time, game points, average speed, distance on 3D space and average acceleration. A testing schedule has been created, composed by Catch for the right hand and for the left hand, Follow for the right hand and for the left hand, Move for the right hand and for the left hand and Grab using both hands, each for two-minutes time with a 15-second pause time in between the games. At the beginning of each schedule, a calibration is made, consisting of positioning the camera angle and the user in the optimal position for playing the above games. At the end of the session, all games statistics and evolution charts can be visualized in the patient profile. The parameters that are quantified by the MIRA testing games are: distance, average acceleration and points (score).

2.3 Reliability

To assess test-retest stability, two sessions of MIRA testing schedule were done for each child from the CP and control group on two occasions at a minimum of 3 days and a maximum of one week apart. The paired t test and Wilcoxon's signed rank test were used as appropriate (paired t-test for parametric variables and Wilcoxon's signed rank test for non-parametric variables) to determine if any significant changes occurred between the test and the retest results. The statistical significance threshold was chosen at a p <0.05. Intraclass correlation coefficients were calculated for the entire study group (CP and control group taken together). The difference between the two assessments was plotted against the average of the two assessments for each participant using the Bland-Altman plots, and 95% of the differences were expected to be less than 2 standard deviations from the mean difference between the two testing sessions.

Internal consistency (homogeneity of the items) was assessed using the Cronbach alpha statistic (alpha coefficient).

2.4 Validity

Construct validity was assessed by comparing the MACS stage with the MIRA assessment using Pearson's and Spearman's correlation coefficients. Logistic regression with the presence of illness was performed in order to assess the ability of the MIRA testing to predict the presence of cerebral palsy.

3. RESULTS

3.1 Participants

The average age in the study group was 7.4±1.9. The average age in the CP subgroup was 7.8±2.4 while the average age in the control subgroup was 7.1±1.6 (p=0.38). The sex ratios were not significantly different between the two subgroups (p=0.45). Two of the children in the CP group had spastic paraparesis, six had spastic tetraparesis and three had a mixed form, spastic and dyskinetic tetraparesis. According to the GMFCS scale, four children in the CP group were stage 1, four children were stage 2 and three children were stage 3. According to the MACS scale, six children in the CP group were stage 1, three children were stage 2 and two children were stage 3. The absolute agreement between GMFCS and MACS was 0.56, with a 95% CI of -0.56 to 0.8. Equal scores for the two scales were found only in four children.

3.2 Reliability

All 27 participants included in the study completed the two MIRA testing evaluations. All intraclass correlation coefficients (ICC) for the points achieved in the seven games included in the MIRA testing were above 0.81, the ICC for the total points being 0.94. For two of the seven games (Catch wrist right and Grab both hands) the average points were significantly higher in the second examination compared to the first examination (p<0.05). All intraclass correlation coefficients (ICC) for the distance achieved in the seven games included in the MIRA testing were above 0.73, the ICC for the total distance being 0.9. For two of the seven games (Catch right wrist and Grab both hands), the average distance was significantly higher in the second examination compared with the first examination (p<0.05). All intraclass correlation coefficients (ICC) for the average acceleration achieved in the seven games of the MIRA testing were above 0.41, the ICC for the total distance being 0.83. For two of the seven games (Catch right wrist and Grab both hands), the average distance was statistically significantly higher in the second examination compared to the first examination (p<0.05).

The Cronbach alpha coefficient revealed a high internal consistency (overall alpha=0.97). Each of the variables taken into account contributed positively to the overall alpha value.

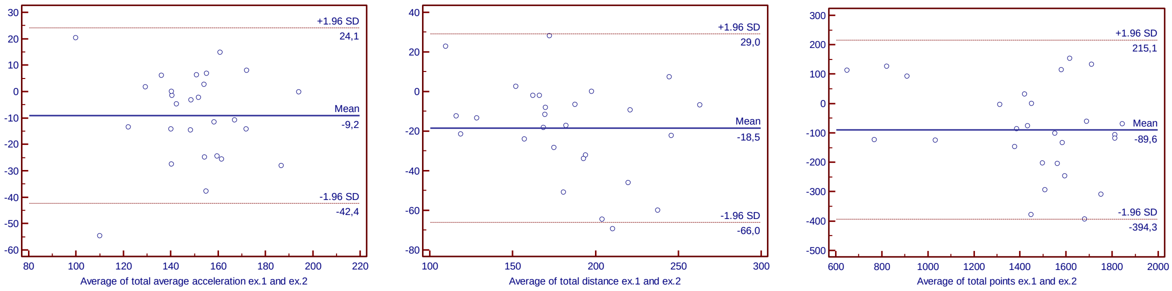

Figure 2. *Bland Altman plots for first and second test results for total average acceleration (left), total distance (centre) and total points (right), for the MIRA testing schedule.*

Bland Altman plots used to test the repeatability of the two examinations revealed that more than 95% of the data plots were placed within the ±2 standard deviations from the mean difference between the two testing sessions for the total average acceleration, total distance and total points (Figure 2). More than 95% of the data plots for average acceleration and points were placed within the ±2 standard deviations from the mean difference between the two testing sessions in each of the seven games.

3.3 Validity

The comparison between the MIRA testing results in the healthy versus the CP group is shown in Table 1. The healthy group achieved higher values of test parameters than the CP group for all the variables. Statistical significance was reached for all the parameters involved in the Catch right wrist, Catch left wrist, Follow right and left wrist points, Move right and left wrist points and for total points. For each of the latter variables, univariate logistic regression with the presence of illness was performed, in order to determine their ability to predict the presence of CP. Those found to be significant predictors of cerebral palsy in the study group are depicted in Table 2. Multivariate logistic regression could not be performed because of the relatively small number of participants (Peduzzi et al, 1987). Since the points obtained in almost every game were found to be predicted for the CP, the ROC curve analysis was performed for the points in order to determine the diagnostic value of the scoring of each game (Figure 3).

Table 1. *Comparison between the MIRA testing parameters in the healthy versus the Cerebral palsy group. The p value refers to the paired t test for the normally distributed variables and to the Mann Whitney test for the non-normally distributed variables. RW= right wrist, LW = left wrist. Normally distributed variables are presented as mean±standard deviation and non-normally distributed ones as median(25-75 percentiles).*

Parameter (distance/points/acceleration)	Healthy (n=16)	CP (n=11)	p
Catch RW distance(m)	40.2±7.8	31.5±7.6	**0.008**
Catch RW average acceleration(m/s^2)	221.6±25.2	191.4±31.4	**0.005**
Catch RW points	229.2±31.2	188.8±47.8	**0.01**
Catch LW distance	42.9±7.5	33.6±9.4	**0.008**
Catch LW average acceleration(m/s^2)	232.4±20.6	196.3±39.9	**0.005**
Catch LW points	221.4±40.3	167.5±57.6	**0.008**
Follow RW distance	17.8±2.3	16.1±2.1	0.07
Follow RW average acceleration(m/s^2)	124.2±14.6	121.7(115.6-127.4)	0.35
Follow RW points	267±14.7	221.8±49.4	**0.0001**
Follow LW distance	17.7±2.4	17.1(15.9-18.5)	0.8
Follow LW average acceleration(m/s^2)	130.4±14.6	124.7±12.1	0.29
Follow LW points	255±16.7	203.1±76.3	**0.0003**
Move RW distance	13.9±4.2	14.1±2.9	0.87
Move RW average acceleration(m/s^2)	100.2±21.7	100±16.9	0.98
Move RW points	156.3±39.3	117±54.3	**0.04**
Move LW distance	14.8±3.76	14.2±2.1	0.59
Move LW average acceleration(m/s^2)	103.9±20.2	108.9(103-113.3)	0.84
Move LW points	158.3±41.2	114.8±51.8	**0.02**
Grab RW average acceleration(m/s^2)	161.1±31.9	154.6±44.5	0.66
Grab LW average acceleration(m/s^2)	163.9±32.3	155.9±42.2	0.58
Grab points	270.7±73.6	248.7±165.1	0.64
Total average acceleration(m/s^2)	154.7±19	143.4±21.6	0.16
Total distance	191.6±34.7	171.2±45.6	0.19
Total points	1557.9±157	1262.4±405	**0.018**

Table 2. *Univariate logistic regression with presence of illness. RW= right wrist, LW = left wrist.*

Parameter (distance/points/acceleration)	Odds ratio	IC 95% interval	P
Catch RW distance	0.84	0.72-0.98	**0.004**
Catch RW average acceleration	0.95	0.92-0.99	**0.007**
Catch RW points	0.97	0.95-0.99	**0.01**
Catch LW distance	0.87	0.77-0.98	**0.006**
Catch LW average acceleration	0.95	0.91-0.99	**0.003**
Catch LW points	0.97	0.96-0.99	**0.007**
Follow RW points	0.94	0.89-0.99	**0.0007**
Follow LW points	0.94	0.91-0.98	**0.0003**
Move LW points	0.97	0.95-0.99	**0.02**
Total points	0.99	0.994-0.999	**0.015**

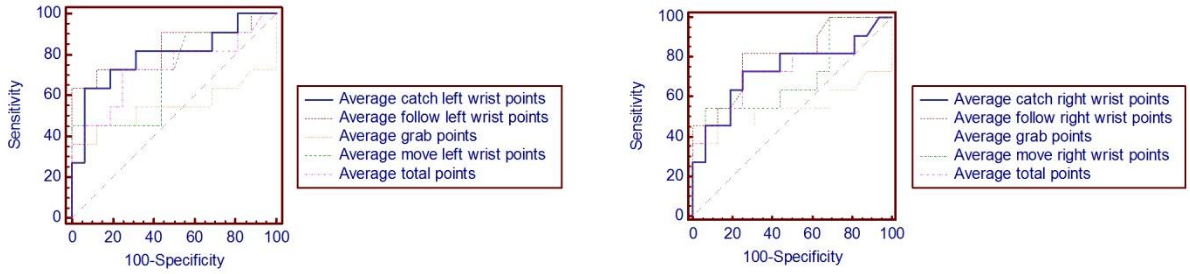

Figure 3. *Comparison of ROC curves for the points in each game for left wrist (left) and in right wrist (right).*

Areas under the ROC curves larger than or equal to 0.8 were found for Catch left wrist points, Follow left and right wrist points. The 95% CI did not contain 0.5 for Catch left and right wrist points, Follow left and right wrist points, Move left wrist points and total points.

Negative correlations were found between the MIRA testing parameters and the MACS stage. The results are shown in Table 3. Statistically significant correlations were found for points in every game except for Grab and Follow left wrist.

4. DISCUSSION

Play is a central part in a child's life. While in early childhood play is characterised by qualities of exploring, participating and imitating, in ages of middle childhood (6-10 years) structured games and organised play predominate (Tamm and Skär, 2000). Interactive video games based on motion capture using Kinect Xbox 360 sensor proved to be efficient in improving balance and activities of daily living in children with CP after 8 weeks of videogame treatment (Luna-Oliva et al, 2013). The idea of assessing body function and performance in children with neurologic impairments using adapted video games is legitimate since these activities are fun and motivational. Thus, IVG could be used not only as a therapy method for children with neurologic impairments, but also for the assessment of motor skills.

In terms of reliability, all of the three parameters (total distance, total average acceleration and total points) had good intraclass correlation coefficients (greater than 0.83). Internal consistency tested with the Cronbach alpha coefficient was high (0.97).

The repeatability of the MIRA testing schedule, assessed by Bland Altman plots, revealed that more than 95% of the data plots were placed within the ±2 standard deviations from the mean difference between the two testing sessions for the total average acceleration, total distance and total points. All data plots for points in each of the 7 games were placed within the ±2 standard deviations from the mean difference between the two testing sessions, suggesting that this was the most reliable parameter of the three. However, the clinical significance of the differences between measurements is yet to be determined in a further study on a larger number of participants and using more game sessions/participant in order to minimize the impact of the learning effect.

Table 3. *Correlations between the MIRA testing parameters and the MACS stages. Pearson's r for normally distributed variables and Spearman's r_s for non-parametric variables.*

RW= right wrist, LW = left wrist.

	Correlation coefficients PCI group n=11		
Parameter distance/points/acceleration (measure unit)	r/r_s	95% IC	P
Catch RW distance (m)	-0.63	-0.9- -0.06	**0.03**
Catch RW average acceleration (m/s^2)	-0.09	-0.7- -0.54	0.78
Catch RW points	-0.74	-0.93- -0.25	**0.009**
Catch LW distance (m)	-0.65	-0.9- -0.09	**0.03**
Catch LW average acceleration (m/s^2)	-0.64	-0.89- -0.07	**0.033**
Catch LW points	-0.69	-0.9- -0.14	**0.02**
Follow RW distance (m)	-0.7	0.92- -0.14	**0.016**
Follow RW average acceleration (m/s^2)	-0.31	-0.77-0.35	0.35
Follow RW points	-0.81	-0.95- -0.43	**0.002**
Follow LW distance (m)	-0.7	-0.92- -0.23	**0.01**
Follow LW average acceleration (m/s^2)	-0.5	-0.85-0.14	0.11
Follow LW points	-0.36	-0.78- -0.31	0.27
Move RW distance (m)	-0.56	-0.87-0.05	0.07
Move RW average acceleration (m/s^2)	-0.09	-0.65-0.54	0.7
Move RW points	-0.6	-0.88- -0.002	**0.049**
Move LW distance (m)	-0.59	-0.88-0.17	0.056
Move LW average acceleration (m/s^2)	-0.15	-0.69-0.49	0.66
Move LW points	-0.5	-0.86- 0.08	**0.05**
Grab RW average acceleration (m/s^2)	-0.53	-0.86-0.1	0.09
Grab LW average acceleration (m/s^2)	-0.5	-0.48-0.13	0.1114
Grab points	-0.5	-0.85-0.13	0.1
Total average acceleration (m/s^2)	-0.57	-0.87-0.05	0.07
Total distance (m)	-0.69	-0.91- -0.14	**0.02**
Total points	-0.68	-0.91- -0.14	**0.021**

Except for the Move game, the points, the average acceleration and the distance were higher in the second examination versus the first one for all children. For two of the MIRA testing games these differences reached statistical significance. These data suggest that a learning effect may be present for all children. Thus, children should probably play several times the MIRA testing games in order to reach their best motor performance. The learning effect was not present in the Move game, which was inspired from the clinical tests for dyskinesia, requiring slow motion, well coordinate movements.

The validity of the MIRA testing schedule is supported by the negative correlation between the MACS classification and the total points achieved. Thus, a higher score was associated to a lower MACS stage. Total points and points in each game except for Grab were statistically significantly higher in the healthy group compared to the CP group. The univariate logistic regression revealed that all the scores gained in each game except for Grab and Move right wrist were associated with the risk of having cerebral palsy. In the ROC curve analysis, satisfactory areas under the curve (higher than 0.8) were found for Catch left wrist points, Follow left and right wrist points. The Grab game showed the smallest area under the ROC curve, associated with the lowest sensitivity and specificity for CP.

One limitation of the current study is the relatively small number of participants. Children with CP and intellectual disabilities are unfit for assessment of motor skills with movement-based IVG and those with MACS stage 4 and 5 are cannot use their hands independently, so they are unable to play. Further studies on a larger number of participants are needed to support our findings.

To our knowledge, this is the first study that aims to develop an occupational therapy scoring system for the assessment of the bilateral upper limb function and performance in children with cerebral palsy using adapted interactive video games and the Kinect 360 Xbox sensor. A future study will test the therapeutic effects of the MIRA games in children with cerebral palsy and will focus on a new version of the MIRA testing schedule in which the Grab game will be excluded.

5. CONCLUSIONS

The scoring of the MIRA testing interactive video games adapted for children with neurologic impairments using the Microsoft's Kinect 360 Xbox sensor of motion seems to be a reliable and valid occupational therapy tool for the assessment of the bilateral upper limb function and performance in children with cerebral palsy. Of all games, Grab seemed to be the least appropriate for this purpose.

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Evaluating the Microsoft Kinect for use in upper extremity rehabilitation following stroke as a commercial off the shelf gaming system

L Shires[1], D J Brown[1], N Sherkat[1], J Lewis[1], P J Standen[2]

[1]Interactive Systems Research Group, Nottingham Trent University,
Clifton Lane, Nottingham, UK

[2]Division of Rehabilitation and Aging, University of Nottingham,
Lenton Lane, Nottingham, UK

luke.shires2007@my.ntu.ac.uk, *p.standen@nottingham.ac.uk*

[1]*www.isrg.org.uk,* [2]*www.nottingham.ac.uk*

ABSTRACT

Motion controlled video games have been shown to have a positive effect for physical rehabilitation on the upper extremity in stroke survivors when combined with conventional physical therapy. While much research in this area has worked with bespoke systems and games, some research has been done into using commercial off the shelf gaming systems (COTS) for use in upper extremity stroke rehabilitation. As COTS systems are designed to be used in the home they offer the possibility of providing survivors with low cost systems that they can use to carry out rehabilitation at home. The Microsoft Kinect for the Xbox360 is a multimodal gaming peripheral used to drive a full body skeletal pose estimation system. This allows users to interact with games using bodily motions and gestures. Unlike other current motion controlled gaming systems the Kinect is marker-less so does not require the user to hold or wear any peripherals. A list of important joint motions and movement synergies were identified by looking at leading stroke motor function tests for the upper limb. These have been verified by working with Occupational Therapists. A study group of Occupational and Physiotherapists were asked to record their experience of playing three Kinect mini-games from the Kinect Sports title and evaluate them with respect to their motor function requirements and exertion for each identified joint motion. Quality information was also gathered relating to the perceived usability and safety issues that could arise by presenting the device to a stroke survivor. Kinect provides opportunities for gross arm movement exercise, while the requirement for highly raised arm movements will present a potential barrier for stroke users. Fine motor control movements of the hand and fingers are not tracked sufficiently for effective rehabilitation of the hand. A probable risk of falling while using the Kinect, and potential injury from overexerting the impaired limb while playing existing games were also identified. We conclude that as the experience have been designed for able bodied users the games present significant barriers for using Kinect as a COTS system for stroke rehabilitation.

1. INTRODUCTION

Stroke is the third most common disease in the UK with over 100,000 cases annually (Bupa, 2011). Stroke is also the leading cause for long term disability (Adamson et al, 2004). The cost of treatment and dealing with the long term disabilities afterwards is estimated to cost the UK economy £8.9 billion per year (Saka et al, 2009). Impaired arm function is a common effect of a stroke seen in around 70% of stroke cases, 40% of patients will have a completely non-functioning arm (Robinson, 2009). Rehabilitation of the impaired limb is key to helping the stroke survivor regain independence. By allowing more stroke survivors to live independently the costs of providing disabled services and care can be reduced.

Physical rehabilitation is concerned with helping stroke survivors to regain control and coordination of the impaired upper limb. This involves direct contact with physical and occupational therapists to help the survivor develop and perform a set of exercises designed to help regain control in the upper extremity. Physical rehabilitation in this way can be limited by the therapist's availability; giving survivors more opportunity for rehabilitation increases the expected recovery (Robinson, 2009). Following discharge from hospital the survivor may be required to travel to outpatient facilities for rehabilitation; this can be problematic for survivors with poor mobility (common following stroke) or who live in remote areas. The sudden and often unexpected stroke will have a significant effect on the survivor's life, making tasks that were once easy extremely difficult. It is therefore unsurprising that depression is common amongst stroke survivors. It is important that the survivor remains motivated and engaged with their rehabilitation especially in the early stages when the expected recovery amount is at its maximum (Wade et al, 1985).

Motion controlled video games have been shown to have a positive effect on physical rehabilitation of the upper extremity in stroke survivors when combined with conventional physical therapy (Baranowski et al, 2008) (Burke et al, 2008) (Burke et al, 2009). These games consist of an input method that requires movement of the upper extremity causing the player to exercise the impaired limb whilst playing the game. The game itself provides a motivational context that is fun and engaging for the player to interact with (Burton et al, 2011). While much research in this area has worked with bespoke systems and games, some research has been done into using commercial off the shelf gaming systems (COTS) for use in upper extremity stroke rehabilitation. As COTS systems are designed to be used in the home they offer the possibility of providing survivors with low cost systems that they can use to carry out rehabilitation at home (Lang et al, 2009). This could allow survivors to exercise at a level they are comfortable with, independent of physical or occupational therapists. It also offers a valuable opportunity to survivors who are unable to frequently travel to outpatient centres to engage with rehabilitation activity. Low cost independent rehabilitation solutions may provide a cost effective way for long term rehabilitation which is currently limited by therapist resources (Moeslundt et al, 2006) (Dam et al, 1993).

Historically the literature relating to COTS gaming systems for use in stroke rehabilitation has focused on two systems, the Playstation Eyetoy and the Nintendo Wii. More recently however, following the launch of the Kinect system in late 2010, there has been a surge of interest in the investigation of Microsoft Kinect and the role it can offer in this context.

The PlayStation EyeToy is a small camera that attaches to the PlayStation 2 gaming system. Functionally it is equivalent to a low cost USB web camera. The device outputs a low resolution colour image. The system then looks for any differences in colour at each pixel over time (between captured frames) to detect any motion at that pixel's location. As the system only looks for motion it is unable to distinguish between the player's movement and any background object. The system does not implement any pose tracking, so is unaware of the player's actual pose or position. To account for this the player is usually asked to stand or sit in a fixed position and use their arms to create the necessary motions. Rand et al (2004) tracked the scores and enjoyment of a group of stroke survivors and a group of healthy elderly users while playing several EyeToy games. Comparing the results showed that both groups found the experience enjoyable and highly motivating. However the stroke group had significantly lower game scores, this can be accounted for by the stroke group reporting fatigue in the impaired limb, preventing them from playing as effectively. It is mentioned that the option to control the speed and difficulty of the games is not present but in this context would be desirable. Yavuzer et al (2008) reported a controlled, assessor blinded trial over four weeks where one group of stroke survivors took part in treatment using the EyeToy. The control group spent the same amount of time observing the game but not partaking. At the end of the four week trial the EyeToy group scored significantly higher when measured with the functional independence measure (FIM).

The Nintendo Wii uses a handheld controller device that can detect its position relative to a sensor bar mounted on the display device and the acceleration force on the controller. Like the EyeToy, the Wii is not able to perform body pose estimation as it can only gather positional information of the controller device. For most games this is assumed to be in the user's hand so can therefore be used to determine hand position. Joo et al (2010) found a slight increase in Fugl-Mayer assessment scores following two weeks of physical therapy using the Nintendo Wii. All subjects found the games enjoyable or very enjoyable. Problems were encountered during the study as some subjects had trouble holding the Wii controller due to poor hand motor control, therefore a custom strap was used to allow the user to 'wear' the controller rather than hold it. Saposnik et al (2010) compares using the Wii to conventional recreational therapy, finding that the Wii offers significant improvement in motor functions measured with the Wolf motor function test. Mouawad et al (2011) also found similar positive results.

The Microsoft Kinect for the Xbox360 is a multimodal gaming peripheral. Its primary input method is a novel low cost ranging (depth) camera that is used to drive a full body skeletal pose estimation system. This allows users to interact with games using bodily motions and gestures. Unlike other current motion controlled gaming systems the Kinect is marker-less so does not require the user to hold or wear any peripherals. The ranging camera allows position estimation in three dimensions allowing complex body poses to be tracked. The accuracy and consistency of the Kinect sensor has been evaluated both in terms of its ability to measure the position of objects (Dutta, 2012) (Shires et al, 2013) and upper body joint rotations (Nixon et al, 2013) These studies suggest that it performs very well. It is however important to acknowledge that under certain circumstances use of the peripheral can be problematic. Some of these limitations are inherently a property of the technology itself. The use of projected infra-red light precludes the use of the sensor in areas of bright natural sunlight and being camera based, occlusion is a big issue, particularly where the hand or arm pose is unconventional due to a disability.

Lange et al (2011) utilised Kinect in a trial for balance training of adults with neurological injury. This study highlighted the difficulty of achieving the "calibration pose" necessary for the skeletal tracking to initialise properly. Of the twenty participants in this study eight were unable to achieve this pose and the remaining twelve required the assistance of a clinician to manipulate the upper limb into a position suitable for calibration. Pastor et al (2012) also noted the problems with supporting the weight of an impaired upper limb, utilising the Kinect in a downward pointing manner so that a table top could provide support. These studies were based upon bespoke software solutions, the current crop of COTS games have the added drawback of also requiring the player to stand while playing, further exacerbating the potential usability issues associated with using the system and raising further questions about whether it has any potential as a COTS device for home rehabilitation. However the study conducted by Chang et al (2011) concluded very favourably in terms of the utility of the device, noting a significant improvement in motor function as well as recording high levels of motivation and recommending further In this paper we present our findings from a study to evaluate the Kinect for safety and suitability as a COTS gaming system for stroke rehabilitation. The study also sought to identify areas that a bespoke system based upon Kinect hardware could improve upon, thereby enhancing the rehabilitation possibilities beyond those available within existing commercial titles. The study's focus was on identifying exercises of interest to upper extremity rehabilitation that are encouraged and facilitated by the system. Full upper extremity rehabilitation requires multiple exercises across a number of joints in the upper extremity. It is important to identify which regions the Kinect is effective at exercising so that its potential as a tool for rehabilitation can be assessed, as well as evaluating the usability of the Kinect device within the physical limitations of a stroke user group. The Kinect system is a full body skeletal tracking system. Games designed for the Kinect are built with able bodied users in mind, therefore as noted by Lange et al (2011) only a subset of available games, or game elements may be usable by a stroke user group with limited physical capabilities.

Safety concerns surrounding usage of the Kinect with a stroke user group were also explored. Stroke survivors with upper extremity deficits commonly have accompanying lower extremity problems, affecting balance and mobility. This can put the stroke survivor at a greater risk of falling. Therapists were asked to assess the presented games to identify if they would put a stroke user at a risk of falling. They were also asked to assess if the Kinect encourages exercises that could have a negative effect on the stroke survivor's recovery.

As Xbox Kinect has over 140 games from first and third party developers only a small number of these could be included into the study due to limited resources and practically of the study duration. Potential games were examined against the following criteria:

- Short experiences that a user is able to learn and play quickly are desirable considering the time constraints of the study.
- A complete round of a game should take no more than a few minutes to complete.
- The game must provide adequate instructions for a non-gamer to easily understand and play.
- The game must remain playable for a user with a low level of physical ability.

Using these constraints the game 'Kinect Sports' was selected. It is perhaps interesting to note that "sports" was a theme requested by participants in the Lange et al study (2011). Kinect Sports (figure 1) is a series of mini games based on real world sporting activities. As such the rules of the games are easy to learn even to non-gamers as they match the real world counterparts. The mini game format allows short game experiences to be played quickly and repeatedly without spending a significant amount of time operating menu systems. From a selection of six mini games two were selected, Bowling and Table Tennis. These were chosen in order to compare a game that requires the user to react in a limited time (Table tennis) with one where the user is given time to cognitively process and plan the activity (Bowling).

2. RESEARCH DESIGN

The study was conducted over several repeated sessions with different occupational therapists. Therapists were allowed to participate individually or in pairs. When in pairs each participant was require to play at least one round of each game individually, while the other observed. Individual participants would watch a demonstration round provided by the session conductor. This was designed to allow participating therapists to observe the system from a first and third hand perspective.

Figure 1. *Kinect Sports for the Xbox360.* [Rare, 2014].

At the beginning of each session the occupational therapists were given a brief demonstration of the Kinect system by an experienced user leading the session. The session conductor demonstrated how to start the Kinect system, navigate to the first game to play, start the game and give a brief demonstration of how to play the game. The system was then restarted and each occupational therapist in turn was asked to perform the start-up steps and play the game for several minutes including at least one full round of the game. After each occupational therapist had a chance to use the system and experience the game they were presented with a questionnaire to gather feedback from their experience. Participants were allowed to continue playing the game during the questionnaire. This processes was repeated for each of the two mini games.

2.1 Population

The purpose of this study is to primarily evaluate if the Kinect is safe for use with a stroke group. Therefore no stroke survivors were involved at any stage of this study. The study population will consisted of qualified occupational and physical therapists with experience of working with a stroke population. Six participants were recruited for the study. All six participants completed the study.

2.2 Data Collection

Data was collected by questionnaires completed by the participants. The questionnaire asked participants to rate the minimum joints functionality required at each joint needed to meaningfully participate in the game, how exerting the exercise on each joint was during play and how much they felt the game encouraged them to use individual joint movements.

Participants were also invited to discuss their experience of playing each game. They were asked to focus on any potential safety issues they could foresee when presenting the Kinect system to a stroke population.

3. RESULTS

To visualise the results they have been graphed to show the mean score, standard deviation and range of the answers given. Of the two games tested, bowling was found to be more suitable for a stroke survivor as it required less arm and shoulder functionality to play. As shown in figure 2 bowling required a moderate to high level of shoulder mobility to play, a moderate amount of elbow movement and very little wrist and hand movement. Comparatively table tennis as shown in figure 3 is far more intensive and requires a much higher level of motor functioning. This could be due in part to the time limitations of each activity. Bowling allows the player to take an indefinite amount of time to bowl each ball. Table tennis by contrast requires the player to make timed reactions to the computer opponent. Cross body movements were required to perform backhand shots, this probably explains the increase in the amount of high intensity shoulder movements required.

Both games required little to no hand and wrist movement. This fits with our understanding of how the skeletal tracking algorithm works as it is unable to track wrist rotations and hand pose. Therefore we would expect games not to require wrist and hand movement as they are unable to detect them. Therapists did however feel that the games encouraged a greater range of joint movements than the system required. As shown in figure 4, therapists found themselves using hand and wrist motions when playing. As the games mimic real world activities the players may feel the need to match the normal movements even if they are not required by the Kinect games. In bowling therapists found themselves making hand grip and release movements when picking up and throwing the ball.

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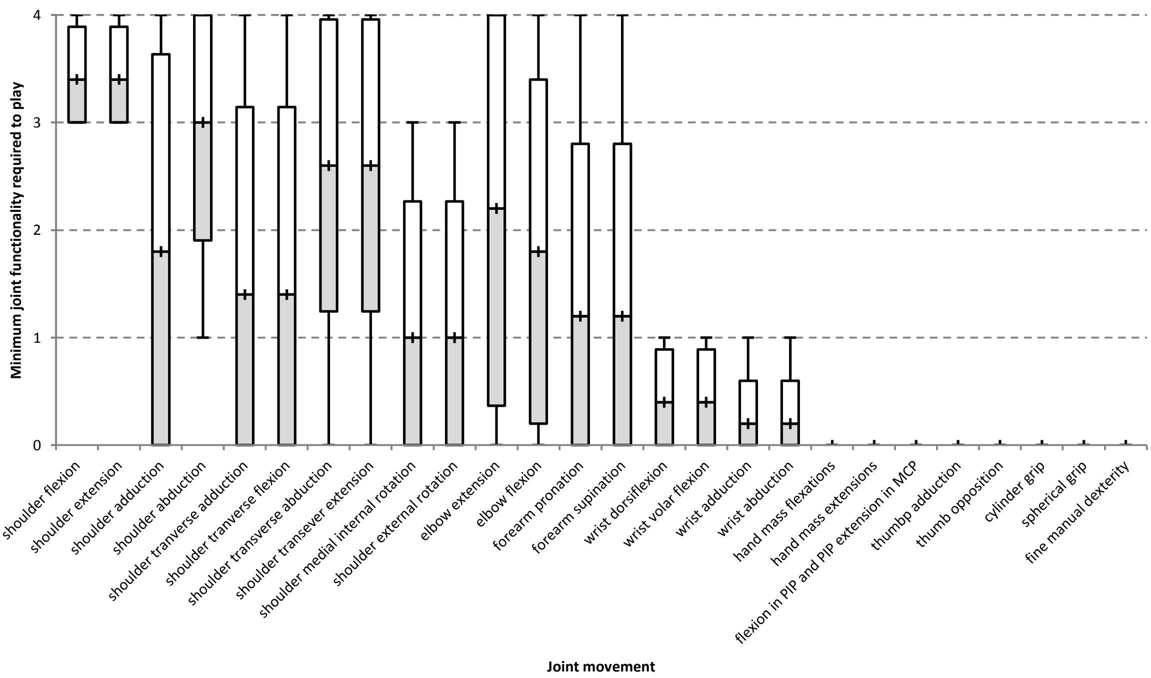
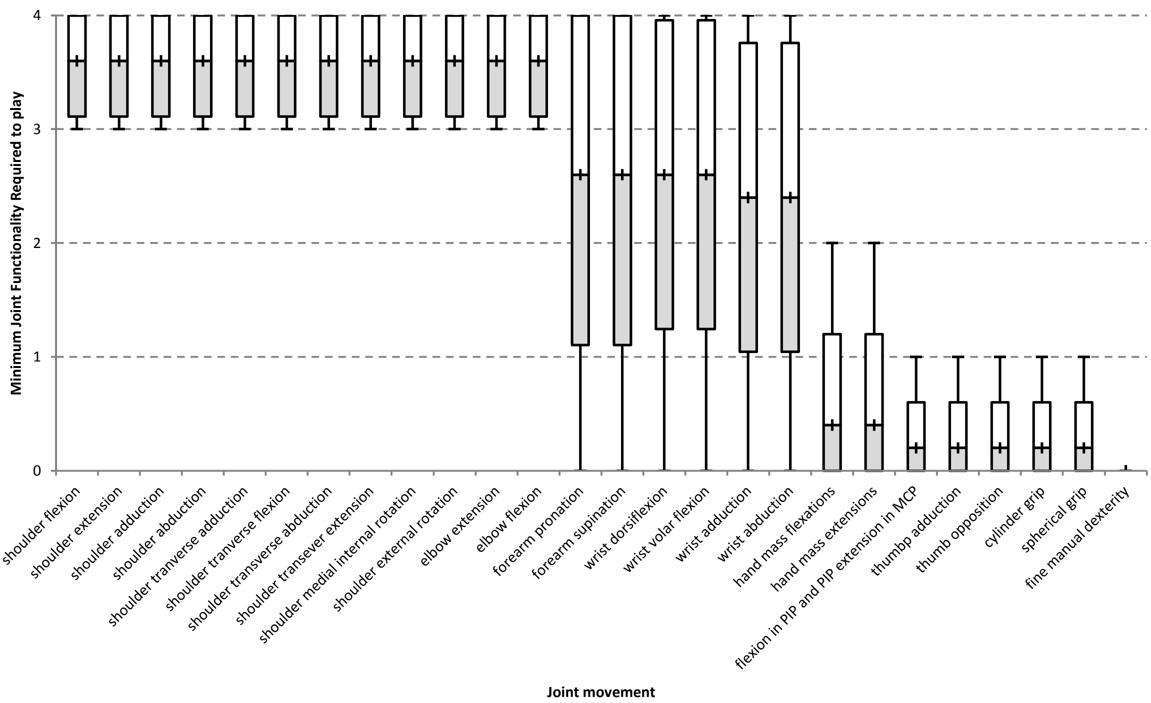


0. No motion required. 1. Reduced range of motion. 2. Partial range of motion. 3. Partial range of motion against gravity. 4. Full range of motion against gravity.

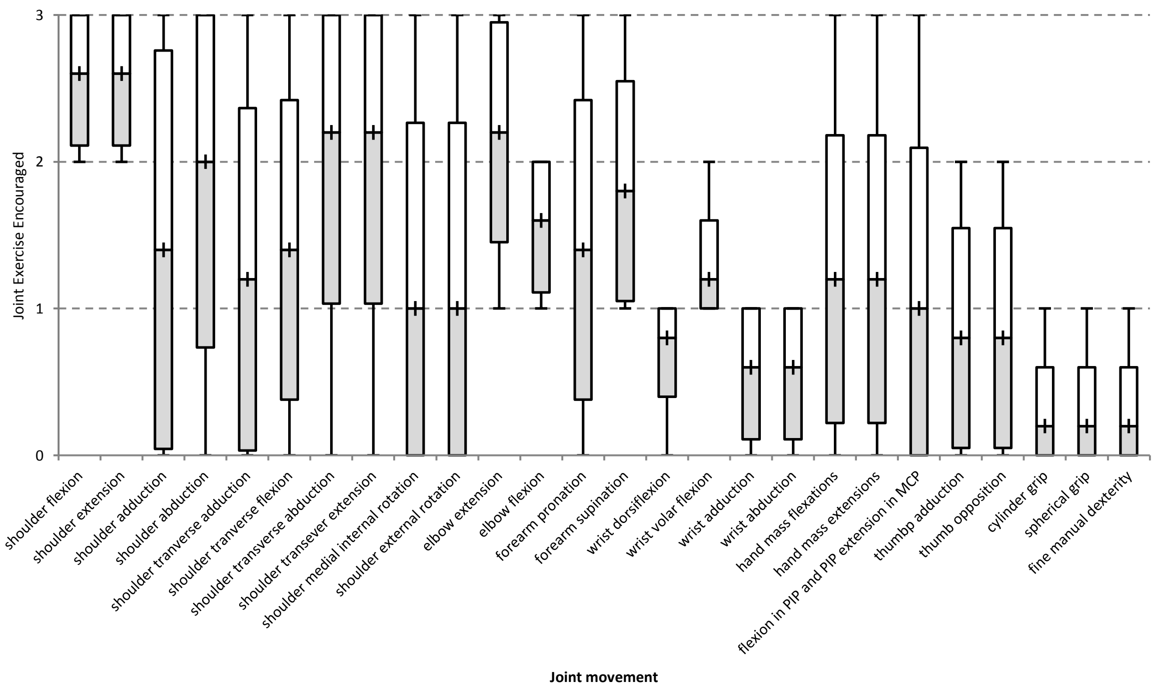
Figure 2. *Minimum joint functionality required to play bowling.*



0. No motion required. 1. Reduced range of motion. 2. Partial range of motion. 3. Partial range of motion against gravity. 4. Full range of motion against gravity.

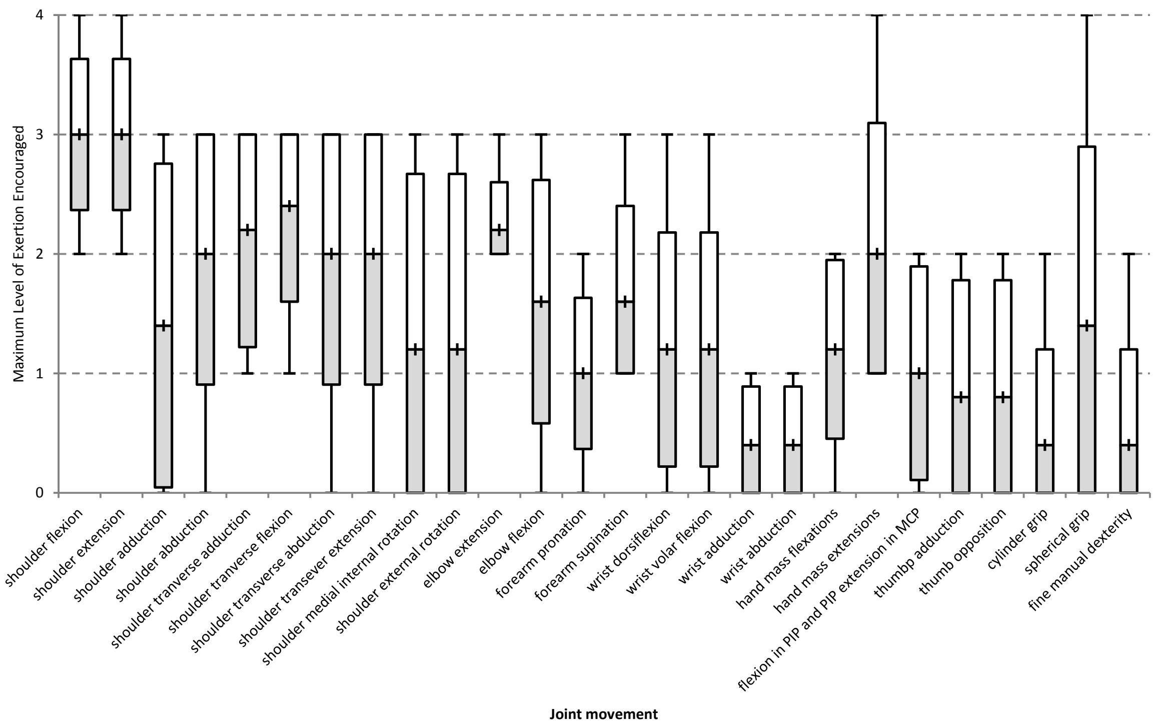
Figure 3. *Minimum joint functionality required to play table tennis.*

By encouraging joint movements in this way the games could provide a wider rehabilitation benefit to more joints in the arm than are traceable by the Kinect camera. However as the joints are not tracked there is no guarantee that the user is performing them. This may be useful in a supervised therapy session where the therapist can observe the patient’s movements. However in an independent usage situation there would be no record of the patient’s hand movements and would be of reduced usefulness for telerehabilitation.



0. Not encouraged. 1. Encouraged but not required. 2. Implicit to fulfilling required task. 3. Explicit to fulfilling required task.

Figure 4. *Joint exercise encouraged for bowling.*



0. No exertion. 1. Low. 2. Medium. 3. High. 4. Dangerous

Figure 5. *Maximum level of exertion encouraged for bowling.*

Therapists were also asked to rate how intensively they were using each joint during play as shown in figure 5. Most joint movements were found to be low to medium intensity. This is good as many stroke survivors will have a weakened upper limb and may fatigue quickly when performing intensive tasks. Shoulder flexion and extension movements were found to be very intensive. This is because the game requires the user to make a large

Proc. 10th Intl Conf. Disability, Virtual Reality & Associated Technologies
Gothenburg, Sweden, 2–4 Sept. 2014
©2014 ICDVRAT; ISBN 978-0-7049-1546-6

swinging movement at the shoulder. This is problematic for a stroke survivor as many will not have the required range of motion. This could present a barrier that they are unable to overcome and thus not be able to use the game.

3.1 *Qualitative Findings*

Therapists were asked to provide additional feedback about their experience. Common feedback included raising concerns about the balance risks while using the device. As the game does not work in a seated position, players must be standing. Many stroke survivors have reduced mobility, placing them at an increased risk of falling. Because of the motor impairments stroke falls can be extremely dangerous as often the victim is unable to break the fall using their upper limb. This makes the Kinect a potentially dangerous system to use for rehabilitation, especially when unsupervised. Several therapists also expressed the desire for seated play as many survivors are unable to stand unaided so could not use the system. When developing bespoke games, allowing them to be played in a seated position should be considered a high priority.

Concerns over the game's graphical interface were also raised. Kinect Sports is designed to mimic sporting television coverage. This includes fast camera cuts and pans; detailed environments including crowds and decorative lighting; and statistical overlays that appear periodically. Cognitive deficit can accompany motor deficit during stroke, and may stroke survivors will not be familiar with video games. Efforts should be made to provide a clearer graphical interface.

4. CONCLUSIONS

The off the shelf Kinect game Kinect Sports was evaluated to assess the feasibility of using it in its current form as a stroke rehabilitation aid. Two games from the title Kinect Sports were evaluated - bowling and table tennis. It was found that both titles were highly exertive on the shoulders and arms, while no wrist, hand or digit functionality was required at all. Although it was felt that wrist and hand movements were encouraged through the context of the exercises, as the Kinect does not track these motions it cannot be guaranteed that the user is performing them during play. Due to the high level of arm functionality required, it is likely that the games would only be useable by stroke survivors who have recovered a significant amount of motor functionality. Qualitative information was also gathered from therapists during the study, who believed the exercises combined with the requirement to stand while playing presented a real danger of fall and injury during play. It is concluded that off the shelf Kinect games are not suitable for most stroke survivors for unsupervised rehabilitation.

Adaptations that could be made to the evaluated games would be to allow play from a sitting position to reduce the risk of a fall and further injury. Kinect sports does not support seated play but a small number of Kinect COTS games do allow this e.g. Fruit Ninja Kinect and Kinectimals. Our results also showed that games require a high degree of joint functionality to play especially with regards to shoulder movements. This limits to potential audience to stroke survivors who have already regained a high degree of joint functionality. This is because the games are designed for able bodied users without accessibility in mind. By altering the game design to reply on less exerting movements would increase the number of users who are able to play. One instance of this is in Kinect Sports Bowling the player is required to hold their arm out to the side to pick up a ball. This is a difficult move and not possible for a large number of stroke survivors especially during rehabilitation. By providing alternative ways to perform these actions would allow people with less arm functionality to participate more.

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Adapting a humanoid robot for use with children with profound and multiple disabilities

P J Standen[1], D J Brown[2], J Hedgecock[3], J Roscoe[4], M J Galvez Trigo[5], E Elgajiji[6]

[1,3,4]Division of Rehabilitation and Ageing, School of Medicine, University of Nottingham, Nottingham, UK

[2,5,6]Interactive Systems Research Group, School of Science & Technology, Nottingham Trent University, Nottingham, UK

p.standen@nottingham.ac.uk, david.brown@ntu.ac.uk, [3]mzyjh1@nottingham.ac.uk, [4]mzyjr@nopttingham.ac.uk, msegtrigo@gmail.com, eelgajiji@umit.edu.ly

[1]*www.nottingham.ac.uk*, [2]*www.ntu.ac.uk*

ABSTRACT

With all the developments in IT for people with disabilities, few interventions have been designed for people with profound and multiple disabilities as there is little incentive for companies to design and manufacture technology purely for a group of consumers without much buying power. A possible solution is therefore to identify mainstream technology that, with adaptation, could serve the purposes required by those with profound and multiple disabilities. Because of its ability to engage the attention of young children with autism, the role of a humanoid robot was investigated. After viewing a demonstration, teachers of pupils with profound and multiple disabilities described actions they wished the robot to make in order to help nominated pupils to achieve learning objectives. They proposed a much wider range of suggestions for using the robot than it could currently provide. Adaptations they required fell into two groups: either increasing the methods through which the robot could be controlled or increasing the range of behaviours that the robot emitted. These were met in a variety of ways but most would require a degree of programming expertise above that possessed by most schoolteachers.

1. INTRODUCTION

With all the developments in IT for people with disabilities, it is disappointing that few interventions have been designed for people with profound and multiple disabilities. A recent systematic review (Kagohara et al, 2013) on the use of iPods, iPod Touch and iPads in teaching programs for people with developmental disabilities noted an absence of studies on individuals with profound and multiple disabilities. Their explanation for this was that this group presents unique challenges with respect to the design of technology-based interventions, a major one being their lack of sufficient motor control to activate the device and software.

There have been some attempts to circumvent this problem of motor control. An extensive body of work by Lancioni (see for example Lancioni et al, 2008) has demonstrated there is a way for almost anyone to activate a microswitch. The most common way is to use a push switch, which is activated by applying pressure to a large button. However they can also be triggered by pressure sensors on the armrest of a wheelchair, by chin or eyelid movement (Lancioni et al, 2005) or by vocalisation (Lancioni et al, 2001). This then allows the user to exert environmental control, activate a piece of equipment which may produce speech on their behalf, or begin a pleasurable stimulus for the user such as playing a piece of music.

There have also been attempts to capture gesture or body movements using infrared sensor-based systems to enable those with multiple disabilities to control multimedia (Brooks, 2011). A more recent development that can allow a profoundly disabled person to interact with their environment has been enabled by the appearance of low cost headsets that enable gamers to interact with games using their own brain activity (Welton et al, in press). Although microswitches can be activated in relatively effortless ways, operating them may still be a challenge to someone with poor postural control and low muscle tone. One teacher in an earlier study (Hedgecock, 2013) commented that, for children with severe physical disabilities, even maintaining their position requires considerable effort. If you are then asking them to learn a new response, an exceptionally attractive reward is going to be necessary.

There is little incentive for companies to design and manufacture technology purely for a group of consumers without much buying power and it has been argued that those with disabilities are reluctant to adopt technology that is designed specifically for them. Reasons for this include the stigma associated with assistive devices as they are believed to be a visible sign that emphasises the difference between them and others and the absence of abilities (Parette and Scherer, 2004). A possible solution is therefore to identify mainstream technology that, with adaptation, could serve the purposes required by those with profound and multiple disabilities. Studies with children with autism (e.g. Werry and Dautenhahn, 1999, Salter et al, 2008, Dautenhahn and Billard, 2002, Robins et al, 2005) found that robots possess qualities that would make them a promising candidate for employment with children with profound and multiple disabilities. Robins et al (2005) report that, unlike interactions with human beings, "interactions with robots can provide a simplified, safe, predictable and reliable environment where the complexity of interaction can be controlled and gradually increased" (p 108). In addition, Robins et al also found from behavioural observations that "children with autism directed significantly more eye gaze and attention towards the robot, supporting the hypothesis that the robot represents a salient object suitable for encouraging interaction".

This latter quality was echoed in an exploratory study (Ibrani, Allen, Brown, Sherkat, and Stewart, 2011) of eight children with either autism, Downs syndrome or severe learning disabilities working with a mobile robotic platform. Klein et al. (2011) showed that working with a robot increased "playfulness", and therefore engagement, in two out of the three young children with developmental disabilities in their study. They describe how engaging children in this way could encourage the development of functional skills. According to Iovannone *et al*. (2003) engagement is "the single best predictor" of learning for children with intellectual disabilities. Discussing children with complex needs, Carpenter (2011) writes that "Sustainable learning can occur only when there is meaningful engagement. The process of engagement is a journey which connects a child and their environment (including people, ideas, materials and concepts) to enable learning and achievement" (p35). For teachers of children with profound and multiple disabilities, achieving their engagement is a big challenge and they have to work hard to attract and maintain a child's attention before trying to teach something. The robot is eye-catching and attractive, novel, responsive, non-demanding, safe and predictable and, if the robot is doing the teaching, is the child's focus more likely to be where it needs to be in order for the learning to take place?

Two recent small scale studies (Hedgecock 2013, Roscoe 2014) investigated the suitability of a humanoid robot to support the learning of pupils with profound and multiple disabilities. Both studies found that engagement rated by teachers using the SSAT Engagement Scale (The Special Schools and Academies Trust, 2011) was significantly higher with the robot than in the classroom. At the beginning of both studies, teachers were asked to identify pupils they thought might benefit from working with the robot, learning objectives they thought the robot would help the pupil achieve and how the robot might help them do this. The teachers proposed many more possible uses for the robot than it could perform in order to provide personalised interventions for individual pupils. Therefore the aims of the current paper are to describe the uses the teachers identified for the robot and how the robot was adapted to enable it to fulfill these roles.

2. METHODS

2.1 Participants

Eleven members of teaching staff from a school in Nottingham with around 150 pupils with severe, profound or complex learning and/or physical disabilities nominated one or two pupils to work with. There were no exclusion criteria for the pupils other than parents not consenting. The 13 boys (age range 5 to 18 years) and 3 girls (age range 11 to 20 years) were some of those with the most complex needs. Most had minimal communication skills and little understanding of words relying on body language, signs and symbols or verbal cues and were described as having a short attention span and being easily distracted. Several had a diagnosis of cerebral palsy but most had delayed fine and gross motor development with low muscle strength, some being reliant on wheelchairs or walkers and some having involuntary movements. Sensory impairments were common, five had epilepsy and one was tube fed and suffering from recurrent chest and urinary tract infections.

2.2 The robot

The robot used in this project was a NAO NextGen (Model H25, Version 4) humanoid robot, which is commercially available from robotics manufacturer Aldebaran Robotics. NAO is manufactured with a wide range of behaviours, including walking, standing up and sitting down, dancing, and recognising speech, sounds and objects as well as producing speech from text and playing sound files. These behaviours can all be programmed into the robot using Choregraphe, a user-friendly graphical interface that allows users to control the robot wirelessly from a laptop or desktop computer and create sequences of behaviours.

Fig 1 shows three of the sections of the control screen of Choregraphe with annotations labelling the various features. The central Flow Diagram Panel initially appears blank for the user to create a sequence of behaviours by dragging and dropping behaviours from the box library on the left. The behaviours that the robot comes with will appear in here. A Behaviour box represents a behaviour, or sequence of behaviours and double-clicking on the box reveals another flow diagram panel, of the smaller behaviours making up one single behaviour. For behaviours that the robot comes with, these will have been written by the manufacturer. However, new behaviours can be added to the robot's repertoire by creating new behaviour boxes grouping together a series of preprogrammed behaviours. Additionally, new behaviours can be written from scratch using computer programming languages recognised by NAO such as C, C++, Java, MATLAB, Urbi, .NET and Python. On the right hand side of the screen is the Robot View Panel which will show a real-time simulation of the behaviour currently being played.

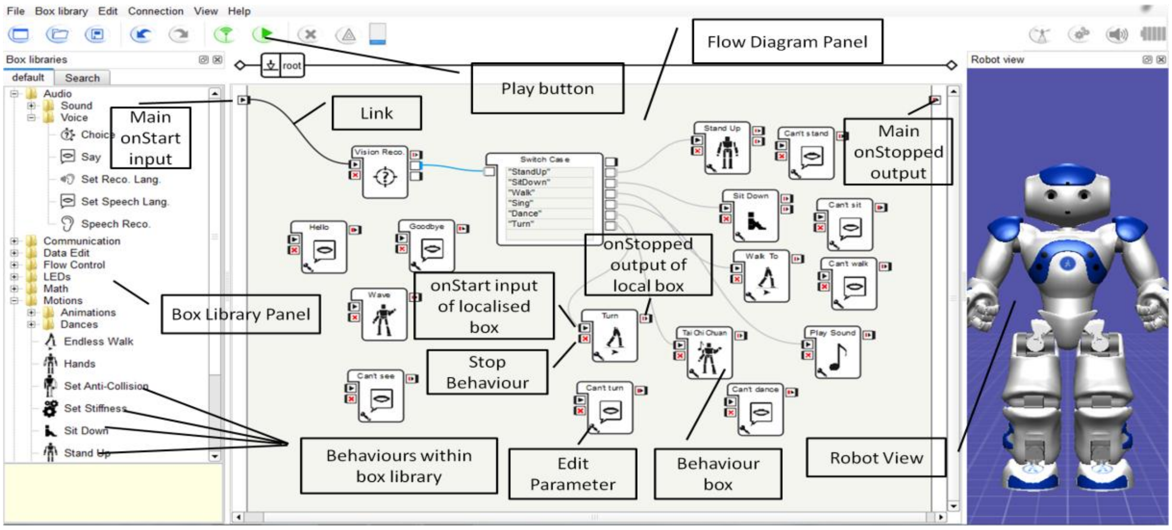

Figure 1. *Three of the sections of the control screen of Choregraphe. For explanation see text.*

2.3 *Procedure*

Teachers were recruited from those that attended a demonstration of the robot at the school given by the research team. In individual meetings with a member of the research team they identified one or two pupils whom they thought would benefit from working with the robot. Discussions were held with the teachers to devise an appropriate learning objective for the pupil to achieve in the sessions and how the robot might be used to achieve this. Some of the actions required were already available in the robot's repertoire but those that were not had to be created in other ways before the final format of the sessions could be individually designed for the pupils, focussing on their interests and learning style, to help them achieve their learning objective.

3. RESULTS

The results are in two parts: first of all a taxonomy of what the teachers wanted the robot to do and secondly how changes were programmed into the robot to enable it to fulfill these requests.

3.1 *What did teachers want the robot to do?*

3.1.1 To produce a behaviour that acted as a reinforcer. When working with this group of pupils teachers tend to use behaviourist techniques more than with other groups of pupils and their requests relied heavily on the concept of reinforcement ie behaviour which is reinforced tends to be repeated (i.e. strengthened); behaviour which is not reinforced tends to die out or be extinguished (i.e. weakened). Teachers identified reinforcers that could be provided by the robot which could broadly be grouped into two categories: behaviours that were appealing or enjoyable in their own right and would act as a reward for completing a goal, or behaviours that allowed the pupil to either achieve a learning objective. Although not primarily intended as a reward, the pupils may still have found it rewarding to complete the activity with the help of the robot or feel empowered by the control which the robot allows them.

Behaviours that were appealing to the pupil or enjoyable in their own right. Examples of these were mostly dancing and playing music. When the pupil makes a response that the teacher requires, this reinforces the link between, at the simplest level, seeing a switch and pressing it, then pressing one with particular symbol. This was initially the case for pupil S2 who the teacher wanted to learn to press a microswitch to learn the association between cause and effect. The robot would reward with a song or dance, phrases like "Well done", "great job", "awesome" or the clapping/cheering app from the robot appstore http://www.robotappstore.com . This basic model could be elaborated on in the following ways:

- *shaping*: another goal for S2 was to make voice commands to control the robot (eg "stand", "sit") but initially the robot was programmed to respond not just to these commands but also to approximations of them (ie "stand up", "get up"). If her utterances were not clear enough, the robot was to respond in a rewarding or encouraging way but to indicate that this was not quite the way the utterance should be (eg "sorry I didn't hear you", "I am an old robot, you have to speak clearly").
- *providing cues*: Verbal utterances from the robot encouraged S7 to use only one hand to trigger the micro-switches
- *inhibiting a response:* For TN, the robot was meant to only respond if the switch were pressed once thus discouraging him from perseverating. For one pupil (S4) the robot was meant to remind him not to be violent as he had a tendency to react in this way.
- *offering choice:* Presenting the pupil with 2 or more switches, with each triggering a different stimulus was planned for teaching the making of choices. By pressing the switch, it was hoped that the pupil would learn that one switch (with a particular symbol or colour) would trigger a stimulus she preferred to the other. The pupil (ST) would then, hopefully, be able to consistently choose the switch triggering the stimulus she preferred, even when the switches were moved around.

Getting the robot to do something to achieve a learning objective. This reinforces the link between pupil action and robot action purely through contingency. However it has the additional benefits of facilitating learning through "action by proxy" rather than through abstract concepts (eg for TH to improve his sense of direction by learning the concepts of "forwards", "backwards", "left" and "right"). This also has the advantage of demonstrating spatial awareness without too much physical activity for someone who may have very limited opportunities for movement. A related example was where S8 learnt to use a joystick similar to that of his electric wheelchair by using it to direct the robot. A different type of learning objective that could be achieved with this application of the robot was exemplified by KW learning the meaning of symbols by showing them to the robot and seeing it respond appropriately. The next stage for KW was to recognise that there must be an order to some actions (e.g. the robot cannot dance when sitting down) and then to put together sequences of up to 4 events taking this into account. While these uses of a reinforcer are described as having no intrinsic reward and differentiated from the first group, it is highly likely that, for someone who has little control over their environment, these behaviours are rewarding in addition to being instrumental in achieving a learning objective.

3.1.2 Robot gives commands. For several of the pupils their learning objectives were either purely to follow commands (eg the robot asked S6 to pick up, throw and pass ball) but could be to help in communication skills (eg ST to repeat what the robot says, thus learning turn taking, see Fig. 2). Similarly, the robot could demonstrate one of S5's physiotherapy exercises encouraging her to touch her ear with her hand prior to pressing the micro-switches. While a human could issue all of these commands, teachers felt that the engaging and consistent nature of the robot might provide a stronger stimulus.

3.2 How to get the robot to fulfil these roles?

3.2.1 Analysing the requirements highlighted that the first problems was enabling the pupil to control the robot. Four of the robot's channels were investigated for their potential route of control:

- Visual recognition. The learning objective for KW (described above) was to learn the meaning of symbols by showing them to the robot and seeing it respond appropriately. For pupils in wheelchairs it was problematic to position the robot and pupil where the robot could see the symbol being presented.
- Auditory recognition. This was utilised with for example, S1 where the teacher's goal was to improve verbal communication. However, the auditory recognition was not advanced enough to consistently recognise the pupil's voices or the auditory output from a hand held computer used by one of the pupils to vocalise words. In these cases the researcher had to resort to using the Wizard of Oz technique.

- Tactile and pressure sensors. The robot has nine tactile and eight pressure sensors at different sites and can be programmed to respond when these are stimulated. However, either pupils were unable to reach these (for example if they were in a wheelchair) or the teacher thought that the pupil's motor control would not enable them to touch the robot with the right level of force.
- Wireless control was already there via the computer but this was only suitable for the researcher or teacher to control the robot. If not using visual or auditory communication, pupils needed a more user friendly way to control the robot. For TH, who was independently mobile, his learning objective was to gain an appreciation of left and right by correctly steering the robot from a start point to an end point. A simple solution was achieved using a smartphone's (Samsung Galaxy Note II) accelerometer as a steering wheel enabled by an app for the phone, and a server for the computer, available from http://www.robotappstore.com.

Figure 2. *ST repeating back to the robot the utterance it has just emitted.*

The majority of pupils were already switch users or their teacher wished them to acquire this skill. One (S8) wanted to learn to use a joystick so that he could control his electric wheelchair with a joystick. In order to allow a switch or joystick to control the robot, Pygame, a cross platform set of Python modules designed for writing video games was used. Pygame is built over a library that allows the use of a high-level programming language like Python in order to structure a program that could be used with several input devices. Next, a piece of Python code was written to produce a virtual server that could act as a bridge between the robot and any input device the pupil required such as Jellybean switches or a joystick. In this way, executing the program corresponding to the server and running the appropriate behaviour in Choregraphe it was possible to control the robot wirelessly with different input devices.

3.2.2 How to get the robot to produce the responses the teacher required.

- Some responses were programmed in already (eg a tai chi dance, the text to speech function which could provide encouragement or cues such as "well done"; "I can't walk when I'm sitting down. I need to stand up first".)
- Some routines were freely available for download from the internet (eg Gangnam Style was downloaded free from youtube and the Macarena dance downloaded free from http://www.robotappstore.com).
- A pupil's favourite piece of music could be found on youtube and made into an audio only file with YouTube converter (http://www.youtube-mp3.org/). Then using an online tool for creating personalised ringtones allowed the song to be cut into the right length making sure that the track starts and ends at an appropriate time. Explicit lyrics were also cut out at this stage!
- More complex behaviours such as kicking a football, were first of all broken down into components and either created from box behaviours already available for the robot or script was written in Python and then included as a box behaviour in Choregraphe.

4. DISCUSSION

When the teachers attended the demonstration of the robot, although a wide range of possibilities were demonstrated, they produced an even wider range of suggestions for using the robot than it could currently provide. The actions they required the robot to make could conveniently be described in behaviourist terms ie the robot would provide reinforcement. However, the wider role they required the robot to take can be seen in terms of the social approach to learning advocated by Wood et al (1976) and also Vygotsky (1987). For young children Vygotsky emphasised the importance of a more experienced adult to mediate their attempts to learn something new. Wood et al used the term “scaffolding” to describe the support given to the less experienced learner and the idea of a scaffold underlines the importance of something temporary that can be removed once learning has taken place. More recently Feuerstein (2006) coined the term “Mediated Learning Experience” to refer to the way in which stimuli experienced in the environment are transformed by a mediating agent, usually a parent, teacher, sibling, or other intentioned person in the life of the learner. Seen this way, the robot is taking on the role of the agent of the experienced person. It has to be emphasised that this role is only possible because of the ability of the robot to engage the pupils (Hedgecock, 2013, Roscoe, 2014), as without engagement there is no opportunity to expose the pupil to the link between their actions and that of the robot.

While initial studies have shown it to be engaging, if schools are going to invest in such an expensive piece of equipment they need to know it has the flexibility to support a wide range of their teaching requirements. Adaptations they required fell into two groups: either increasing the methods through which the robot could be controlled or increasing the range of behaviours that the robot emitted.

In terms of methods through which the robot could be controlled, currently the auditory recognition is not sophisticated enough to be used to meet the learning objectives identified by the teachers. Visual capacity was appropriate for symbols if the pupils could be enabled to position the symbol in a way that the robot could pick up. For pupils in wheelchairs this was difficult unless the robot was on a table in front of them but then this restricted the space the robot had to operate in. The most successful adaptation was enabling the robot to be controlled by a switch. A specific solution to this was found but in order to allow the use of a range of control devices (eg tablet, X box, steering wheel) a more universal solution is required.

One of the authors (MJGT) is currently developing an application for mobile devices that will allow them to remotely operate different robots. It will also allow the teachers to launch prebuilt behaviours or build new ones combining them to meet the learning objectives for each pupil. This would be done directly from a tablet PC or mobile phone, bypassing the requirement for a computer running Choregraphe or being connected to the Internet. Initially the application will be designed and tested with the NAO robot used in this study and tablet PCs running the Android operating system. The next step will be to adapt it for use with different robots and operating systems (such as iOS or Windows Phone). This application will also include a set of games or activities based on findings from this study and earlier work that will aim to help the development and learning skills of children with intellectual disabilities via interaction with the robot.

5. CONCLUSIONS

The humanoid robot used in this study possessed the qualities teachers required to engage pupils with profound and multiple disabilities: it was eye-catching and attractive, novel, responsive, non-demanding, safe and predictable. Teachers came up with a much wider range of suggestions for using the robot than it could currently provide and adaptations they required fell into two groups: either increasing the methods through which the robot could be controlled or increasing the range of behaviours that the robot emitted. These can be met but require a degree of programming expertise above that possessed by most school teachers.

Acknowledgements: Thanks to all the teachers and pupils who took part and to Dr Anne Emerson from the School of Education, University of Nottingham, for her comments on the manuscript.

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Assessment of convalescent brain-damaged patients using a virtual shopping test with different task difficulties

S Okahashi[1,2], H Mizumoto[2], A Komae[3], K Ueno[3], M Yokoyama[4],
A Nagano[5], K Seki[6], T Futaki[1], Z W Luo[2]

[1]Division of Occupational Therapy, Department of Human Health Sciences, Graduate School of Medicine, Kyoto University, Kyoto, JAPAN

[2]Department of Computational Science, Graduate School of System Informatics,
[6] Department of Rehabilitation Science, Graduate School of Health Sciences,
Kobe University, Kobe, JAPAN

[3]Department of Rehabilitation Medicine, [4]Department of Neurology,
Nishi Memorial Port Island Rehabilitation Hospital, Kobe, JAPAN

[5]Faculty of Sport and Health Science, Ritsumeikan University, Shiga, JAPAN

[1]*okahashi.sayaka.7c@kyoto-u.ac.jp*, [2]*luo@gold.kobe-u.ac.jp*, [3,4]*nmpr-riha@koyukai.or.jp*
[5]*aknr-ngn@fc.ritsumei.ac.jp*, [6]*ksekikb@yahoo.co.jp*

[1] *www.med.kyoto-u.ac.jp/en/*, [2]*www.research.kobe-u.ac.jp/eng-ro-man*

ABSTRACT

We developed a Virtual Shopping Test for realistic cognitive assessment using virtual reality technology. The objective of this study was to investigate differences in task performance, brain activation, and subjective assessments in relation to the task difficulty level. Subjects were asked to buy two specific items in Task 1, four items in Task 2, and six items in Task 3 at a virtual mall. The tasks and questionnaires were conducted by convalescent brain-damaged patients and healthy adults. Hemodynamic changes in the prefrontal cortex (PFC) during activation due to the tasks were examined using functional near-infrared spectroscopy. The mean total time was longer for the patients than for the healthy subjects in all tasks. PFC responses in the patients were greater in Task 2 than in Task 1. The patients subjectively evaluated these tasks as more difficult than healthy adults. Although task performance as well as PFC responses were not significantly changed in the healthy adults, they could subjectively evaluate differences between the three task levels, whereas the patients could not, which indicated that patients could not clearly distinguish between differences in the difficulty of the tasks performed. Taken together, the results suggest that the difficulty of the 4-item shopping task may have been sufficient to cause brain activation in the brain-damaged patients.

1. INTRODUCTION

As one of the most serious problems in an unprecedented aged society, the percentage of elderly people with various physical and mental diseases is increasing. Higher brain dysfunctions due to brain damage and aging lead to many difficulties in daily life. However, it is reported that results of conventional neuropsychological tests sometimes disagree with the cognitive function level in real life of the patients (Chaytor et al, 2006; Ord et al, 2010). Therefore, an environment that is similar to everyday life conditions is important for evaluating and training cognitive functions. As a consequence, a focus has recently been placed on virtual reality (VR) techniques.

In cognitive rehabilitation, exercises with an appropriate difficulty level for each individual may increase the patient's motivation and produce good results. However, difficulties have been associated with establishing an appropriate task level because of the lack of evidence on its effectiveness (Cicerone et al, 2011). Although various VR techniques have been proposed for cognitive rehabilitation (Zhang et al, 2003; Knight et al, 2006; Kang et al, 2008), a small number of study including a virtual action planning supermarket considered the task difficulty level and/or related brain activation (Josman et al, 2009; Tarnanas et al, 2012).

We previously developed a Virtual Shopping Test (VST) for a realistic assessment of cognitive function using VR technology (Okahashi et al, 2013). In the present study, the VST was modified to a revised version (VST-R) that had three different task difficulty levels. Subjects were asked to buy specific 2 items, 4 items, and 6 items in a different virtual mall in each task. The system could also output event signals that were synchronized with the user's PC operation. We used these signals to assess event-related brain activation.

The objective of this study was to investigate the differences on task performance, brain activation and subjective assessment in relation to the task difficulty level. VST-R was conducted and questionnaires were answered by convalescent brain-damaged patients and healthy young adults. Hemodynamic changes in the prefrontal cortex (PFC) during activation due to the tasks were examined using functional near-infrared spectroscopy (fNIRS): a non-invasive technique. A previous study reported that executive function and attention were related to activation of the PFC (Godefroy, 2003). We hypothesized that each task level would activate the brain differently and lead to more subjective assessments. In addition, differences were expected in the activation pattern between the two groups.

2. METHODS

2.1 The Virtual Shopping Test-Revised (VST-R)

The hardware system included a personal computer, touch screen (LCD-MF222FBR-T, I-O DATA), and 16-channel OEG-16 fNIRS system (Spectratech Co., Yokohama, Japan). Figure 1 shows the experimental system with VST-R screen and fNIRS channel arrangement on the forehead. A visual environment consisted of a Japanese shopping mall was developed with Metasequoia and Open GL. The width of the virtual mall was about five meters and the depth was about one hundred meters. An audio environment of natural sounds associated with a shopping mall was also provided. By touching the bottom of the screen, users could move forward and turn back in the virtual shopping mall, enter a shop and buy an item. Two hint buttons (e.g. List and Bag) were provided to allow users to view some hints during the shopping task. The operation of buttons was recorded automatically, and outputted as a log file after finishing the test. In addition, this system output event signals when users entered/exited the shop, bought an item, and checked the shopping list. fNIRS data was also recorded with these signals.

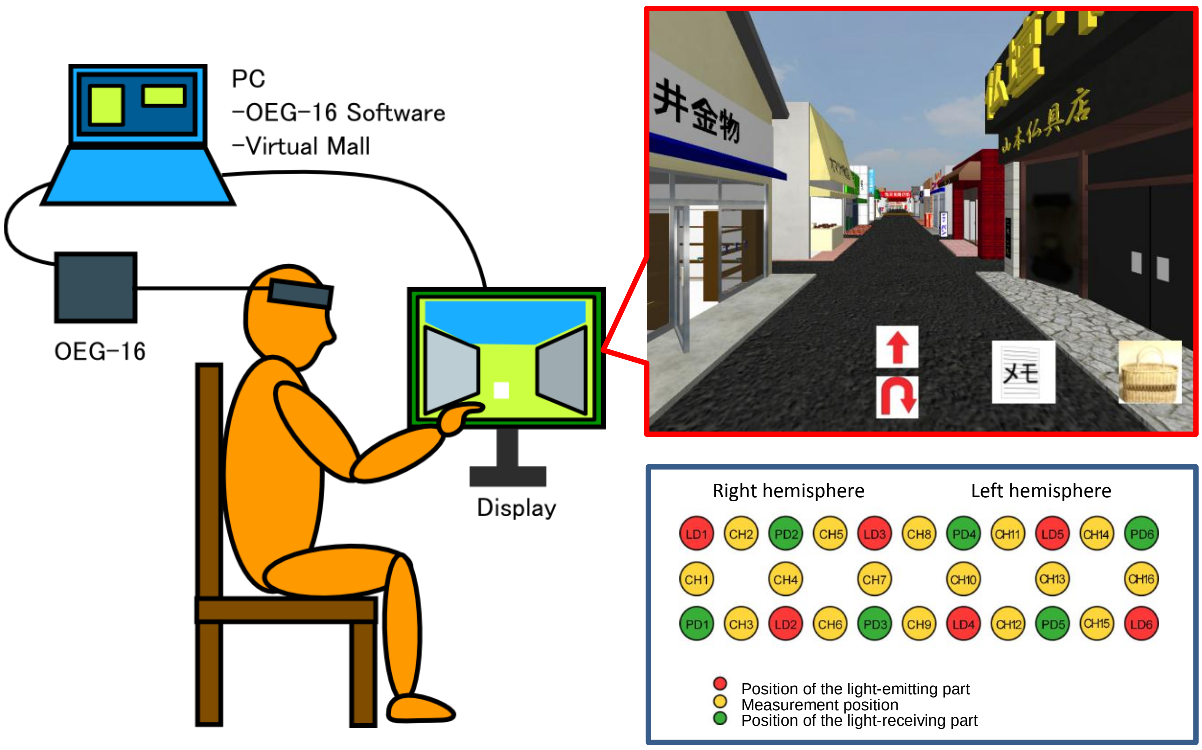
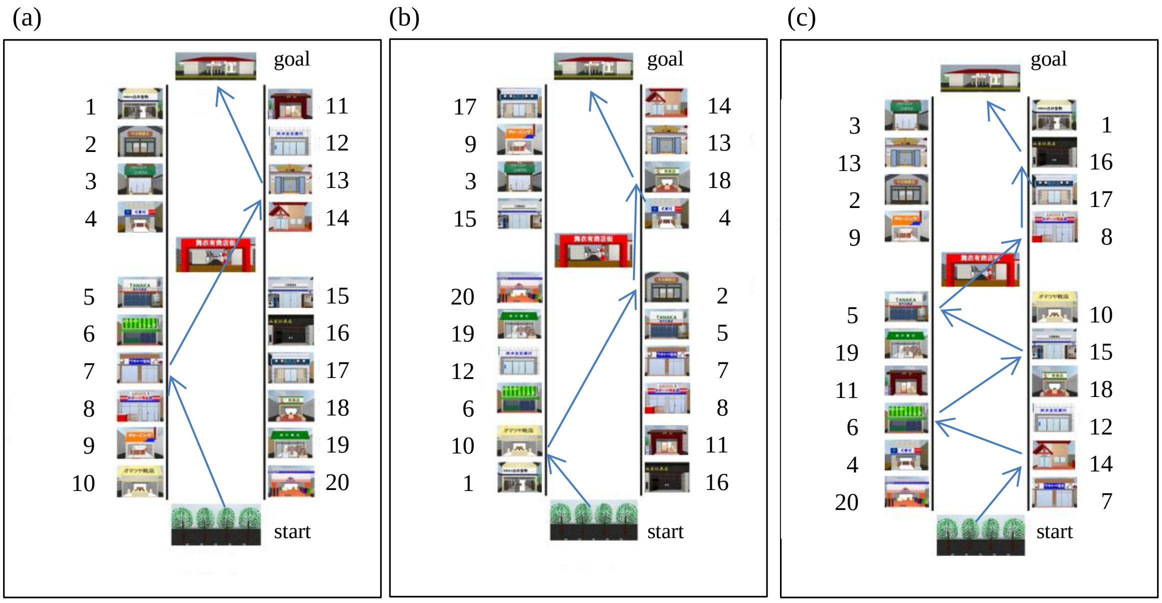


Figure 1. *Experimental system with VST-R screen and fNIRS channel arrangement on the forehead.*

Proc. 10th Intl Conf. Disability, Virtual Reality & Associated Technologies
Gothenburg, Sweden, 2–4 Sept. 2014
©2014 ICDVRAT; ISBN 978-0-7049-1546-6

The fNIRS system was used at a sampling time of 0.65 seconds, the intensity of the light detected at two wavelengths, 770 and 840 nm, was measured, and changes in the optical density were calculated. The system then calculated changes in the concentration of oxygenated hemoglobin [oxyHb], deoxygenated hemoglobin [deoxyHb], and total hemoglobin [totalHb] based on the Beer–Lambert approach. Emission and detection probes were bilaterally attached to the forehead of each subject. The detection probes were set at Fp1 and Fp2, which corresponded to the international 10–20 system of electrode placement with emission probes. Channels covered the bilateral PFC.

2.1.1 Task setting. We constructed a virtual shopping mall in a virtual space, and set up three different tasks with different difficulties. Figure 2 shows three kinds of map and shopping list used in each task. The virtual shopping mall used in each task had twenty shops and a train station, whereas the arrangement of these shops in the mall differed between tasks. The bottom of the map was the start point, while the top was the goal. Task 1 asked subjects to buy two specific items, Task 2 asked them to buy four specific items, and Task 3 asked them to buy six specific items on each shopping list. Subjects had to search the shops that sold specific items and select the target item from six items inside the shop. The blue arrow routes mean the most efficient shopping order in Figure 2.



(a)

<Shopping list >
- a pudding
- AAA-sized batteries

(b)

<Shopping list >
- tomatoes
- rubber boots
- an alarm clock
- a teacup

(c)

<Shopping list >
- an eraser
- plum liqueur
- incense sticks
- building blocks
- an 80-yen stamp
- a baseball glove

1: hardware store, 2: chinaware shop, 3: flower shop, 4: pharmacy, 5: stationary shop, 6: toy shop, 7: electric appliance shop, 8: sporting goods shop, 9: laundry, 10: shoe store, 11: bakery, 12: bank, 13: candy store, 14: post office, 15: liquor shop, 16: Buddhist altar fittings store, 17: watch store, 18: fruit and vegetable shop, 19: bookstore, 20: tailor's shop

Figure 2. *Maps of the shopping mall and shopping lists used in each task: (a) that for Task 1, (b) that for Task 2, and (c) that for Task 3. The blue arrow routes showed the most efficient shopping order.*

2.1.2 Experimental procedure. The subjects were first asked to memorize the specific shopping items while looking at the shopping list for 10 seconds. They were then allowed to plan the shopping routes that they considered to be the most efficient by filling in a blank map sheet with a pencil. They were asked to buy the specific items as quickly and efficiently as possible, while minimizing the use of hints. They were allowed to refer to a blank map at any time during the VST-R.

2.1.3 Outcome variables. VST-R had eight outcome variables: the number of times subjects used each button on the screen (Bag use, List use, Forward movement, and Reverse movement), the number of items bought correctly (Correct purchases), Total time, Time in the shops, Time on the road, and those could be calculated from the recording data automatically.

2.2 Data Collection

2.2.1 Participants. Seven brain-damaged inpatients with cognitive dysfunctions in the convalescence rehabilitation ward and six young healthy subjects participated in this study. The participant characteristics were presented in Table 1. Patients included some forms of brain damage experienced within six months from onset. The participation criteria for the patients were as follows: 1) cognitive ability to understand how to operate a touch screen and 2) physical ability to reach and touch the screen by their uninvolved upper limbs. The study exclusion criteria were as follows: i) severe aphasia, and ii) severe unilateral spatial neglect. All participants received written and verbal information about the study and gave written informed consent. The protocol of the study was approved by the Kobe University Graduate School of System Informatics Ethic Committee and Nishi Memorial Port Island Rehabilitation Hospital Ethic Committee.

Table 1. *Participant characteristics.*

	Patients (n=7)	Healthy subjects (n=6)
Gender (M: F)	4: 3	4: 2
Age	62.0 ± 19.3	23.2 ± 1.0
Duration of education (years)	14.9 ± 1.7	16.8 ± 1.0
Disease duration (days)	102 ± 54.3	—
Diagnosis	stroke: 3 traumatic brain injury: 2 encephalitis: 2	—
MMSE	27.4 ± 1.7	—

M: male, F: female, MMSE: Mini-Mental State Examination

2.2.2 Procedure. All participants were administered VST-R in the order of Tasks 1, 2, and 3 and questionnaires concerning subjective assessment after each task. The questionnaire consisted of three questions concerning the degree of task difficulty, the effort required, and psychological load. Each answer was rated on a five-point scale (1-5). Higher scores indicated higher load task. Patients also performed seven conventional neuropsychological tests and two questionnaires. The general cognitive level was evaluated using the Mini-Mental State Examination (MMSE). Attention was evaluated by the Symbol Digit Modalities Test (SDMT) (Smith, 1991) and Simple Reaction Time Task (SRT) (Beck et al, 1956). Regarding visual inattention, the presence of USN was assessed by Star and Letter Cancellation Tasks (Ishiai, 1999). Everyday memory was assessed using the Rivermead Behavioural Memory Test (RBMT) (Wilson et al, 1985) and Everyday Memory Checklist (EMC) (Kazui et al, 2006). Executive function was evaluated by the Zoo Map Test and Dysexecutive Questionnaire (DEX) (Wilson et al, 1996). All tests were finished within one month before and after the execution of VST-R.

2.3 Data analysis

We reset the data at the two points when subjects start to memorize shopping items and perform VST-R for fNIRS data analysis. We used a low pass filter (cut-off frequency 0.05 Hz and attenuation slope 40dB/Oct). We used Ch4-6 data as the right PFC (rPFC), Ch7-10 data as the medial PFC (mPFC), and Ch11-13 data as the left PFC (lPFC). The average change in [oxyHb] in each PFC area was calculated for memorizing phase: while subjects memorized the shopping items, and VR phase: while they operated the touch screen and were in a shop and on the road in the virtual mall. A task difficulty level (Task 1, Task 2, Task 3) × group (patient, healthy) ANOVA was conducted for behavioral data analysis. Descriptive statistics were also performed in this study due to the small sample size.

3. RESULTS

3.1 Cognitive assessment in the patients

The cognitive assessment data of the patients was presented in Table 2. They all had difficulties in their instrumental activity of daily living. The cognitive dysfunctions were related to more than one aspects of ability: attention, memory, and executive function.

Table 2. *Patient characteristics in cognitive assessment.*

Cognitive test	median	the minimum - the maximum
Attention		
SDMT (%)	30	17 - 42
SRT: correct rate (%)	93.8	68.8 - 100
Star cancellation task /54	54	51 - 64
Letter cancellation task /40	37	35 - 39
Memory		
RBMT: standard profile score /24	14	9 - 22
EMC /39	12	2 - 25
Executive function		
Zoo Map Test: the 1st trial /8	5	0 - 8
Zoo Map Test: the 2nd trial /8	8	4 - 8
DEX /80	8	1 - 41

3.2 Behavioral data

A comparison of VST-R performance between the two groups was presented in Figure 3 and 4. All seven patients accomplished Task 1, six patients could do Task 2, and five patients could do Task 3. A patient who needed the longest time (552 seconds) to complete Task 1 got lost in the mall and bought the same item twice. Another patient did not complete Task 2 by using hints and the map efficiently and needed some assistance from a tester. The number of purchases in each task was not sufficient or excessive for some patients. The mean numbers of Bag/List use and Forward/Reverse movement were larger in the patients than for the healthy subjects in all tasks.

The mean time required to complete the task was longer for the patients than for the healthy subjects in all tasks. The results of ANOVA showed a significant main effect of Task difficulty level and Group at the time required, but no interactions, except for that of the Task difficulty level × Group interaction with Time in the shops. The Total time and Time on the road were longer in Task 3 than in Task 1. Time in the shops in Tasks 2 and 3 was longer in the patients than in the healthy subjects. However, there was no main effect and no interaction for other variables.

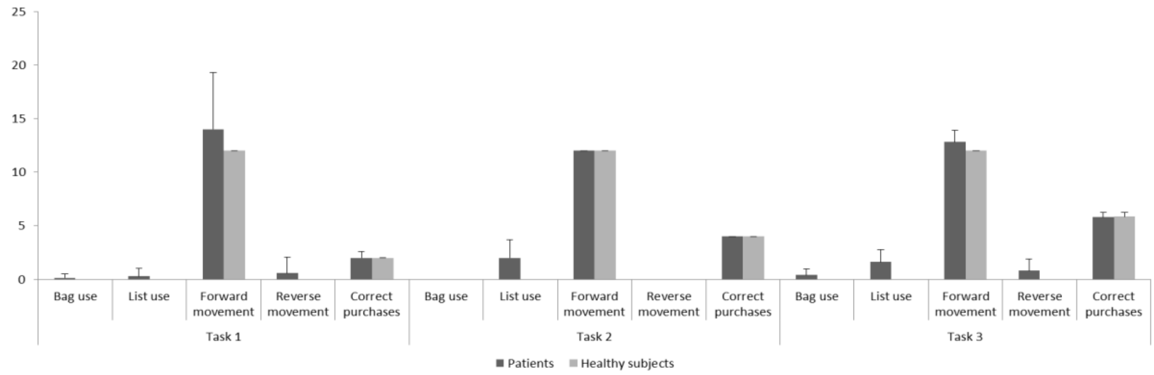


Figure 3. *Comparison of VST-R performance between the patients and healthy subjects (1).*

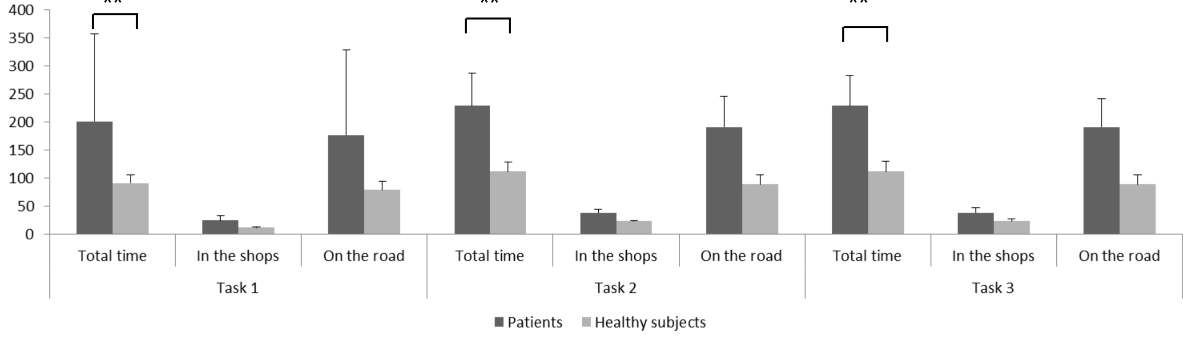


Figure 4. *Comparison of VST-R performance between the patients and healthy subjects (2). ** p < 0.01*

3.3 fNIRS data

Figure 5 shows mean changes in [oxyHb] (Δ[oxyHb]) in each area of PFC in the two groups. We analyzed data obtained in four patients and five healthy subjects in consideration of small artifacts and an older age range for the patients. In the patients, Δ[oxyHb] increased in rPFC in Task 1, increased slightly in mPFC in Task 2, and increased in all PFC areas in Task 3 in the memorizing phase, while it decreased largely in Tasks 1 and increased in Tasks 2 and 3 in all PFC areas in the VR phase. In the healthy subjects, Δ[oxyHb] increased in rPFC in Task 1 and increased in all PFC areas in Tasks 2 and 3 in the memorizing phase, while it increased in r/lPFC in Task 1, increased in rPFC and decreased in mPFC in Tasks 2 and 3 in the VR phase.

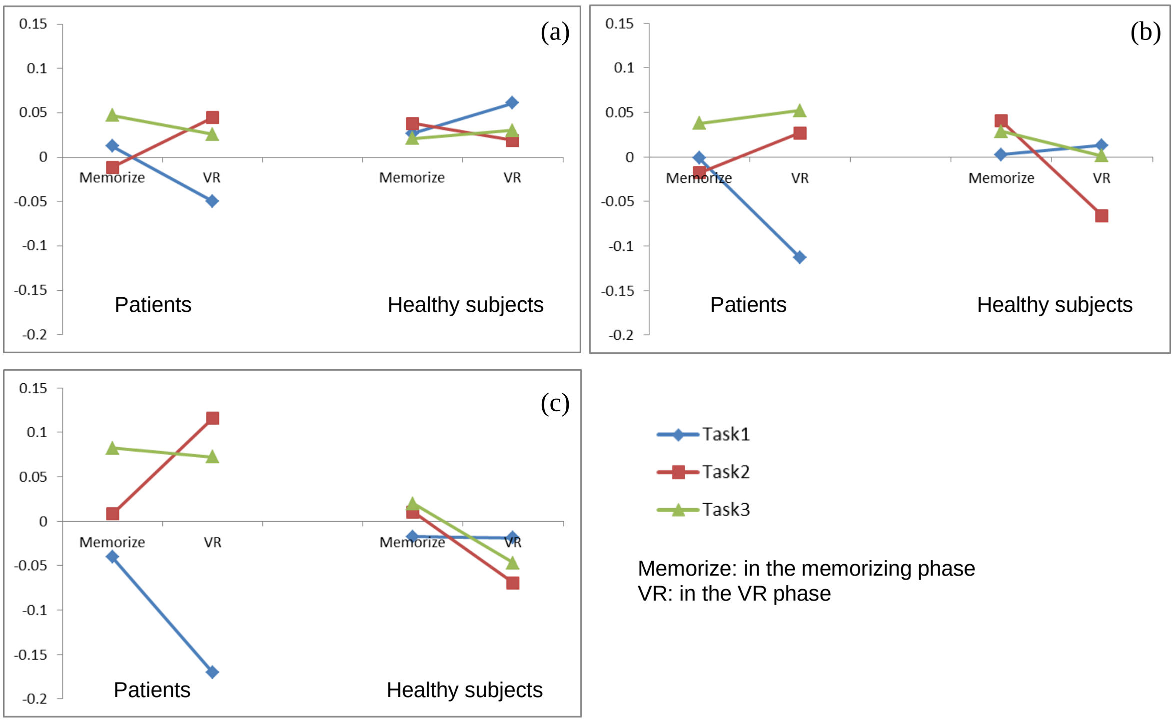


Figure 5. *Mean changes in the concentration of oxygenated haemoglobin in each PFC area: (a) right PFC, (b) left PFC, and (c) medial PFC.*

3.4 Subjective Assessment

The comparison of subjective assessments between the two groups was presented in Figure 6. Higher scores indicated a higher load task. All three assessment items were higher for the patients than for the healthy subjects in each task. The mean scores were higher for the patients than for the healthy subjects in all items. The mean scores on *task difficulty* were 3.0 ± 0.6, 3.9 ± 0.7, 4.0 ± 1.2 for the patients and 1.2 ± 0.4, 2.5 ± 0.8, 3.7 ± 0.5 for the healthy subjects (Tasks 1, 2, and 3, respectively). The mean scores on *efforts made* were 2.9 ± 0.9, 4.1 ± 0.7, 4.4 ± 0.5 for the patients and 1.2 ± 0.4, 2.3 ± 0.5, 3.7 ± 1.0 for the healthy subjects, respectively. The mean scores on *psychological load* were 3.0 ± 1.0, 3.9 ± 0.7, 3.4 ± 0.9 for the patients and 1.2 ± 0.4, 2.2 ± 1.0, 3.0 ± 1.4 for the healthy subjects, respectively.

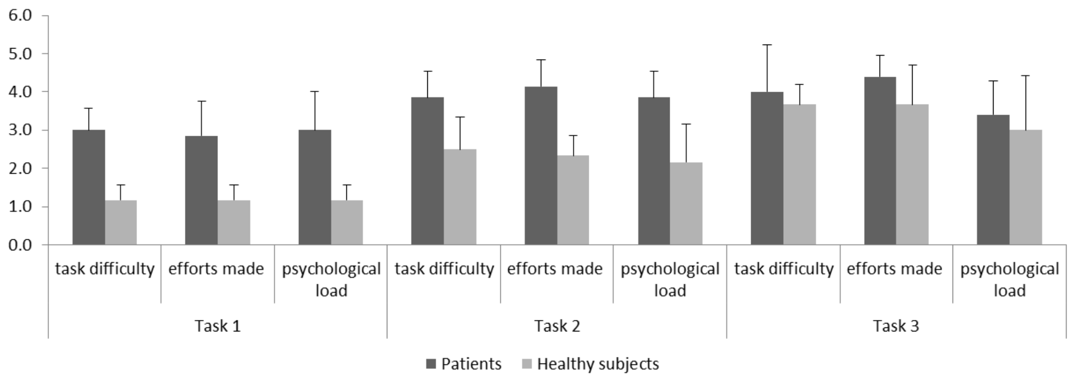


Figure 6. *Comparison of subjective assessments between patients and healthy subjects.*

Proc. 10th Intl Conf. Disability, Virtual Reality & Associated Technologies
Gothenburg, Sweden, 2–4 Sept. 2014

4. DISCUSSION AND CONCLUSIONS

The objective of this study was to investigate differences in task performance, brain activation and subjective assessments in relation to different task difficulty levels in convalescent brain-damaged patients and healthy young adults.

Regarding the VST-R performance, some patients could not accomplish Tasks 2 and 3. We considered they should start exercise from this difficulty level. One old patient needed more time to accustom herself to the virtual mall and its operation. A comparison between the two groups revealed that the mean time required to perform the test was significantly longer for the patients than for the healthy subjects. We considered that VST-R variables, including the number of correct purchases and the total time were important for cognitive assessment. On the other hand, some times when the list was used were regarded as natural behaviour; therefore, and it may be possible to use VST-R in memory rehabilitation with useful compensation strategies.

Regarding brain activation, the pattern of brain activation was particularly different between the two groups in Tasks 1 and 2. Small difference was observed in Δ[oxyHb] in each task for the memorizing phase between the two groups; however, Δ[oxyHb] in the VR phase in Task 1 in all PFC area was lower and it in Task 2 was higher in the patients than in the healthy subjects. These results also suggest that the difficulty levels of Tasks 2 and 3 may have been sufficient to cause brain activation in the brain-damaged patients in this study. Since our sample size was small, we need to amass more data with patients with similar diagnosis and investigate brain activation in relation to the task level in more detail in our next study. In healthy young adults, small increases were observed in Δ[oxyHb] in only right PFC in all tasks for the both phases. It indicated that even 6-item shopping task did not reach their upper limit.

Regarding subjective assessments, patients considered all tasks to be more difficult and required a stronger effort than the healthy subjects. The patients had a subjectively heavier psychological load in Tasks 1 and 2 (2-item and 4-item shopping task) than healthy adults. In addition, although the healthy subjects could recognize the differences between the three task levels, the patients could not. Therefore, we consider that therapists should take subjective mental load on patients into consideration because it may be important to evaluate changes in the exercise phase for more effective rehabilitation.

The results of the present study suggest that, although large differences were not observed in the task performances or PFC responses of healthy subjects at different task levels, they could recognize the differences between the three task levels subjectively, whereas the patients could not, and this indicated that the patients could not subjectively distinguish differences in the three tasks. VST-R is applicable to convalescent patients with higher brain dysfunctions in cognitive rehabilitation, and performing a 4-item/6-item shopping task activated their PFC especially in the interacting with VR environment phase. The easiest 2-item shopping task may be applied clinically by taking into consideration their behavioral errors and mental load.

Acknowledgements: We express our appreciation to the subjects who participated in this study. The authors are grateful to Yohei Mori, OT, Kyosuke Nishizawa, OT, and Fumiko Tsuzuki, ST, for clinical data collection. We thank Tomohiro Kuroda, phD and Motomi Toichi, phD, MD, for their constructive comments on this study. This research was supported by KAKENHI; Grant-in-Aid for Scientific Research (C) (24500643) and Osaka Gas Group Welfare Foundation.

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Case study series using brain-training games to treat attention and memory following brain injury

B B Connor[1,2], C Shaw[2]

[1]Independent Practice in Neuropsychology, Nevada City, CA, USA

[2]Sierra Nevada Memorial Hospital, Grass Valley, CA, USA

bonnie@bonnieconnor.com, cindy.shaw@snmh.dignityhealth.org

www.bonnieconnor.com

ABSTRACT

Rehabilitation following acquired brain injury typically focuses on regaining use of the affected lower and upper limbs. Impairment of cognitive processes, however, is predictive of rehabilitation outcomes. Cognitive activities have become more readily accessible to the home user through web-based games that engage brain functions often disrupted by acquired brain injury. With cognitive testing, it is possible to "prescribe" brain training that targets the specific cognitive functions disrupted by an individual's acquired brain injury. Previous research has shown that individuals with acquired brain injury have difficulty finding the time to train on cognitive tasks at home, and are often confused and overwhelmed when attempting to operate computers without assistance. We asked if computer-based braining training were made available in a structured training format, at no cost to the participant, would acquired brain injury survivors benefit from using commercially available brain training? Three acquired brain injury patients were recruited. Pre and post training psychometric measures of memory and attention were obtained, as well as qualitative evaluation of the user experience.

1. INTRODUCTION

Rehabilitation following acquired brain injury such as 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 (sustained and divided attention, short-term verbal and visual memory, abstract reasoning, comprehension, and judgment) however, predicts length of inpatient stay as well as the number and frequency of referrals for outpatient and home therapies (Galski et al, 1993). Cicerone et al. (2010) found remediation of attention deficits after TBI should include direct attention training and metacognitive training to promote development of compensatory strategies and to foster generalization to real world tasks. This meta-analysis found direct attention training through repeated practice using computer-based interventions might be considered as an adjunct to treatment when there is therapist involvement. Regarding memory training, the task force continued to recommend training in the use of external compensations (including assistive technology) with direct application to functional activities for persons with moderate or severe memory impairment after TBI or stroke

Cognitive activities have become more readily available to the community dwelling user through the availability of web based brain training games that engage brain functions often disrupted by acquired brain injury. 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).

The ACTIVE study started a revolution in computer-based brain training games for normal individuals. Computer-assisted training for brain injury had been available since the 1970's (Lynch 2002). While the initial application of video games was for therapeutic recreation, by the mid-1980s, the IBM PC and Macintosh were available and clinicians began to develop rehabilitation applications for cognitive retraining following traumatic brain injury, which showed positive results in areas such as attention training (Shaw and McKenna, 1989, Park and Ingles 2001). It was only after research demonstrated that brain training could stem the tide of age-related cognitive decline that "brain fitness" became the focus of computer-based brain training. Currently there is a range of commercially available brain training games for normal adults to use to improve or maintain cognitive function. In contrast to programs designed for patient populations, these commercially available brain-training games are priced to be accessible to the general public. The pricing structure and commercial availability of these programs makes them more accessible to patient populations. There is a growing body of research using commercially available brain training games to treat acquired brain injury (Zickefoose et al, 2013, Kessler et al, 2013, Finn and McDonald, 2011). This study examines the therapeutic value for individuals with acquired brain injury of computer-based brain training designed for normal adults, in combination with metacognitive training.

Lumosity (www.lumosity.com), a web based suite of brain training games grounded in the neuroscience of brain plasticity, was selected for this single case series study. Decades of research in brain plasticity, the ability of the brain to remodel itself in response to changes in sensory inputs, has demonstrated the capacity for intact areas of the brain to take over for damaged areas (Jenkins and Merzenich 1987, Pascuale-Leone and Torres 1993, Buonomano and Merzenich 1998, Hallett 1999, Johansson 2000, Harvey 2009). The damaged areas may also be capable of recovering some of their lost function (Cramer et al. 2011). Research has demonstrated that gray matter, the neuronal cell bodies and supporting structures in the brain, can thicken in response to us or shrink due to lack of use—"use it or lose it" is a fundamental principle of brain function. Neural connections can be created and honed through practice or can deteriorate and disappear when not used. When the physical brain changes due to acquired brain injury, cognitive abilities change—most often for worse, not better. Neuroplasticity research has demonstrated the brain's ability to sharpen degraded sensory inputs and revitalize function (Pascual-Leone and Torres 1993, Tallal et al. 1996, Erickson et al. 2007, Berry et al. 2009, Dux et al. 2009).

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 acquired brain injury 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.

The aim of this study was to examine the ability of community dwelling patient's with acquired brain injury to use and benefit from commercially available computer-based brain training games designed for unimpaired adults. We were particularly interested in each individual's ability to improve visual attention and memory using computer-based brain training in combination with metacognitive training, and the effects of these improvements on function in daily life.

2. METHOD

2.1 Design

This study utilizes a single case A-B-A design (i.e. pre-testing, intervention phase, post-testing) in the context of an outpatient treatment setting. All testing in the treatment setting was administered once at baseline and once following completion of training. Each participant was his or her own control. Participants received 24 sessions of training on Lumosity during group speech therapy. Participants were encouraged to train on Lumosity games outside of their speech therapy sessions.

Patients came to the outpatient NeuroRehab Department at Sierra Nevada Memorial Hospital two times per week for 60 minutes for a total of 12 weeks. Each training session included 15 minutes of metacognitive training by the speech therapist to promote development of compensatory strategies and foster generalization to real world tasks, followed by group discussion for psychosocial support. Each session included 15-20 minutes of Lumosity Training Program games, and 15-20 minutes of free play on any Lumosity games selected by each individual. Training took place in a group setting. Patients trained on either a computer or tablet using the Lumosity web site games for attention and memory. Lumosity Brain Performance Test subtests (BPT) were completed pre/post. These are computer-based tests modeled on standardized neuropsychological test that produce a composite score. Following completion of training the semi-structured interview was conducted with each patient.

2.2 Participants

Patients were recruited for the study from individuals with acquired brain injury who were receiving out patient speech therapy at Sierra Nevada Memorial Hospital. Patients included in the case series met the following criteria: 1) adult over age 18, 2) with acquired brain injury, 3) receiving out patient speech therapy services from Sierra Nevada Memorial Hospital, 4) with adequate vision (corrected or uncorrected) to see a standard computer or tablet screen, 5) with adequate upper extremity mobility to use a computer or tablet keyboard, 6) ability to use a computer or tablet 45-60 minutes 2 times per week for 12 weeks (no prior computer experience required), and 7) willing to respond to semi-structured interview questions. Each patient gave informed consent to participate in the study. Dignity Health Institutional Review Board waiver was obtained to present anonymized case study results.

Patients were excluded who: 1) had compromised cognitive ability such that they were unable to comprehend instructions regarding computer or tablet use, or were unable to comprehend training instruction, 2) were physically unable to view computer or tablet screen for up to 60 minutes 2 times per week for 12 weeks, 3) were physically unable to use a computer or tablet keyboard, 4) were unable to commit to training 2 times per week, 60 minutes per session, for 12 weeks.

Three individuals completed the program. Patient A is a 34-year-old male high school graduate with some college coursework who worked in a military skilled occupation. He fell 13 feet while at work in May 2013, landing on the back of his head. He suffered a traumatic brain injury with brief loss of consciousness that resulted in headaches, blurred vision, and difficulty with attention and concentration. He has returned to work less than full time on modified duty. Patient B is a 60-year-old male high school graduate who completed 3 to 4 years of trade school and was self-employed in a skilled occupation. He was in a motor vehicle accident in 2008 in which he suffered a severe traumatic brain injury, as well as multiple bone fractures. He continues to have problems with memory and attention. He has not returned to work. Patient C is a 66-year-old female with 16 years of education who worked in a professional occupation. She had surgery in July 2012 to remove a brain malformation that was causing seizures. The surgery removed her left hippocampus. She has not worked since the surgery. She has memory problems with acquiring new learning.

2.3 Neuropsychological Measures

Neuropsychological testing included Woodcock Johnson Cognitive Abilities (WJ III) subtests Pair Cancellation, Verbal-Auditory Learning Immediate and Delayed, and Lumosity Brain Performance Test (BPI) 7 Subtest Composite score. Pre and post training performance was evaluated in the areas of: 1) psychosocial functioning using the Barkley Functional Impairment Scale (BFIS-Self and Other Report, 2011), 2) visual attention using the Woodcock Johnson Tests of Cognitive Abilities (Woodcock et al, 2001) Pair Cancellation subtest, 3) visual memory using the Woodcock Johnson Tests of Cognitive Abilities Verbal-Auditory Learning and Delayed subtests, 4) composite computer-based brain training overall cognitive performance using a composite score of 7 subtests from the Brain Performance Test (BPT) in the Lumosity (www.lumosity.com) program.

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

Participant	WJ-III Verbal-Auditory Learning	WJ-III Verbal-Auditory Delayed	WJ-III Pair Cancellation	Lumosity Brain Performance Test (BPT)
A	50%	14%	18%	45%
B	7%	8%	23%	10%
C	21%	7%	49%	16%

2.4 Intervention Materials

2.4.1 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. 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 (Figure 1), memory involves spatial recall, *n*-back recall (Figure 2), 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, and quantitative reasoning (Hardy and Scanlon, 2009).

Figure 1. *Lost in Migration. This game challenges attention and response inhibition. The game is used for avoiding distraction, increasing work productivity, and improving concentration. This screen shot appears courtesy of Lumosity.*

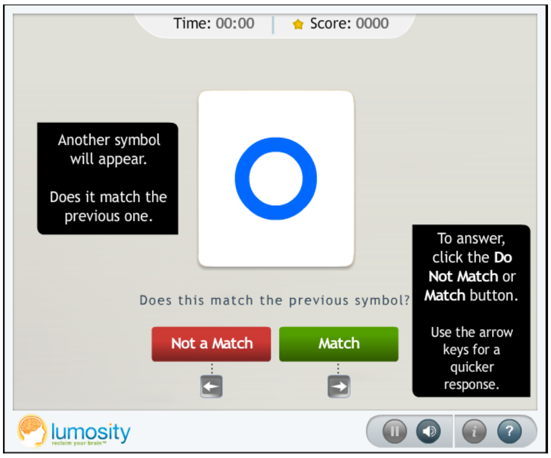

Figure 2. *Speed Match***.** *This game challenges processing speed and reaction time. It is based on the n-back task. Speed training is designed to improve the ability to think quickly, accurately, and pay attention while others are talking. This screen shot appears courtesy of Lumosity.*

Participants were provided with a unique user name and password for access to the Lumosity web site (www.lumosity.com) research portal. Participants trained on Lumosity games two times per week for 30 to 40 minutes per session in the NeuroRehab Lab. Each participant also had access to the Lumosity games outside the structured twice-weekly training sessions. Each participant was invited to play the games as often as possible. All participants completed the 24-class session training in the NeuroRehab Lab.

2.4.2 Metacognitive Training and Psychosocial Support. Metacognitive training included 1) memory compensation techniques, 2) types of memory, use of checklists, and routines, 3) strategies to reduce unwanted auditory, visual, and anxiety related distractions, 4) strategies to maximize depth of understanding for new material and optimize learning, 5) compensatory strategies to reinforce recall at the community level including note taking tools, session agendas, and handouts. Psychosocial training included 1) symptom management and coping strategies for headache, frustration, dizziness, feeling overwhelmed, 2) sharing among participants compensations and strategies for symptoms, 3) recognizing strengths and weakness about specific injury, learning about mechanism of injury, and how that translates into cognitive and emotional issues, 4) checking in about concerns, likes and dislikes, and 5) expressing frustrations with the games.

2.5 Semi-Structured Interview Questions

Following completion of the 24 session training, participants were asked to respond to the following questions: 1) what was your overall impression of the cognitive computer games, 2), what did you enjoy about working with computer cognitive games, 3) what were the challenges involved in training, 4) how has the training affected your day to day life?

2.6 Analysis

Pre/post training quantitative analysis is graphically displayed. Thematic analysis (Braun and Clarke, 2006) was used to analyze the semi-structured interview data. Video interviews were conducted with all 3 participants.

3. RESULTS

3.1 Quantitative Results

Age-related percentile scores pre and post training are displayed graphically for each participant. All participants experienced improvement on Woodcock-Johnson III outcomes measures with the exception of Woodcock-Johnson III Pair Cancellation. *Participant A* showed decline in the BPT composite score following Training. The Barkley Functional Impairment Scale (BFIS) was used as a self- and other-report measure of the impact of acquired brain injury on instrumental activities of daily living. This instrument did not produce reliable data in the overall analysis. One participant did not have a collateral that knew her well and she misunderstood the instructions regarding pre-injury assessment of her functional abilities. Neither the participants, nor their collaterals, rated composite functional abilities in the impaired range post injury; therefore pre/post training scores were uninformative.

3.1.1 Participant A showed improvement on all outcomes measures with the exception of WJ-III Pair Cancellation and Lumosity Brain Performance Test.

3.1.3 Participant C showed modest improvement on all outcomes measures with the exception of W-J III Pair Cancellation.

3.1.2 Participant B showed modest improvement on all outcomes measures.

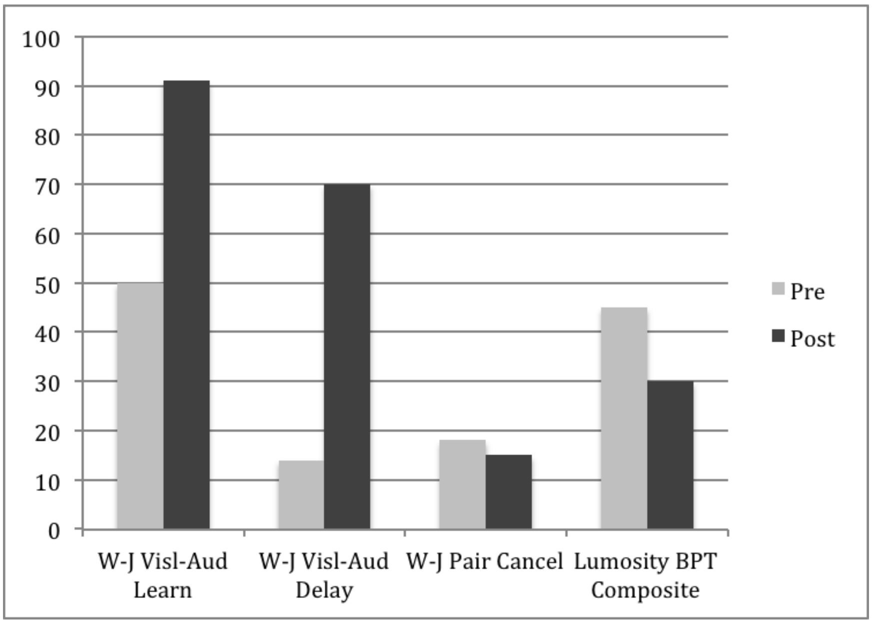

Figure 3. *Participant A's pre and post training performance expressed in age-related percentile scores on the Woodcock-Johnson III Tests of Cognitive Abilities Visual-Auditory Learning, Visual-Auditory Delayed, Pair Cancellation, and Lumosity's Brain Performance Test.*

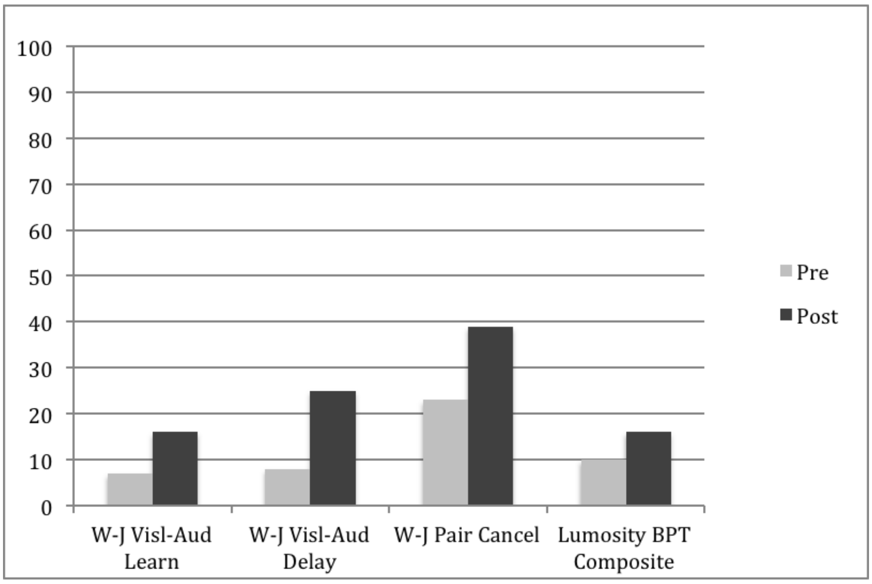

Figure 4. *Participant B's pre and post training performance expressed in age-related percentile scores on the Woodcock-Johnson III Tests of Cognitive Abilities Visual-Auditory Learning, Visual-Auditory Delayed, Pair Cancellation, and Lumosity's Brain Performance Test.*

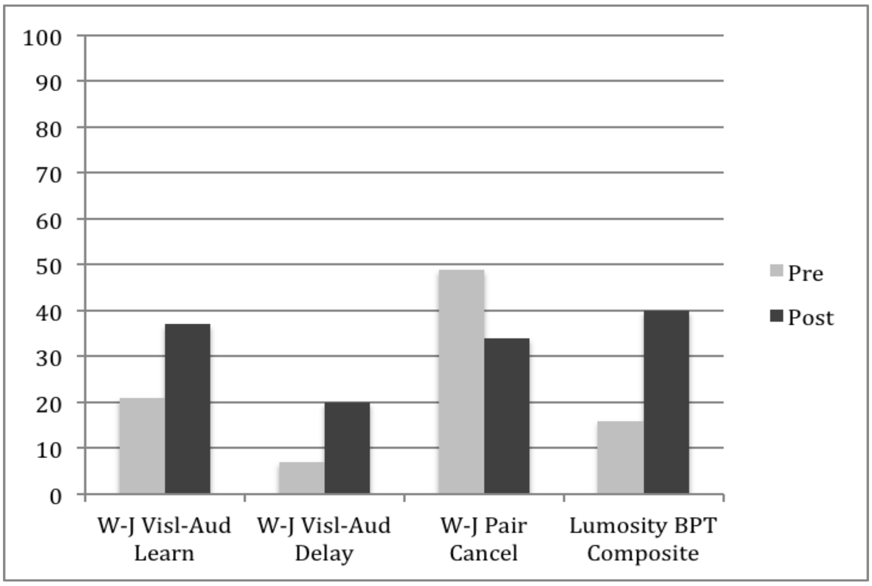

Figure 5. *Participant C's pre and post training performance expressed in age-related percentile scores on the Woodcock-Johnson III Tests of Cognitive Abilities Visual-Auditory Learning, Visual-Auditory Delayed, Pair Cancellation, and Lumosity's Brain Performance Test.*

3.2 Qualitative Analysis

Semi-structured interviews were completed with each of the 3 participants following completion of 24 sessions in the NeuroRehab Computer Lab. Participants were asked to give an overall impression of the cognitive computer games, what they enjoyed about working with computer cognitive games, what were the challenges, and how did the training affect day to day life. Three themes emerged when examining participation: brain engagement, remembering to remember, and cognitive processing efficiency.

3.2.1 Brain Engagement. Participant A found the game training improved critical thinking skills. When allowed to engage in 'free play,' he trained on games that improved his spelling skills important for his work. He enjoyed the opportunity to "exercise" his mind, however found the training games to be repetitive and wanted more variety. He questioned whether his scores on the computer games got better "because my brain got better or I simply got better at the game." *Participant B* found the games were engaging and offered him "new things to help out" his brain function. He described some games as "fun" and enjoyable. *Participant C* found the games "engaged me, pulled me into something helping my brain." She looked forward to game play and to receiving feedback about her game performance.

3.2.2 *Remembering to Remember*. *Participant A* found the comprehensive training program helped him develop strategies to compensate for attention and memory problems following brain injury, and facilitated his ability to remember to remember information important in his daily life. *Participant B* reported being able to "remember things better." "Things are coming back to me quicker, better—I'm remembering things better." He is remembering to focus on memory in his day-to-day life. *Participant C* reported the game play gave her confidence that her "memory is improving." She described the game training as getting her "into the flow of using my memory." She expressed the opinion that her memory was being helped in "a subtle way" as a result of game play.

3.2.3 Cognitive Processing Efficiency. *Participant A* found computer-based brain training improved the speed and efficiency with which he processes new information. *Participant B* found cognitive processing efficiency was diminished by spending too long on the computer or playing games that were too challenging, which led to headaches. *Participant C's* impression was that her "mental flexibility" and "thinking" were improving as a result of computer-based brain training.

4. DISCUSSION

All participants completed the 24 sessions of training in a supervised treatment setting. Unlike participants post acquired brain injury who were unable to complete training in their own homes (Connor and Standen, 2012), these individuals benefited from a structured environment that included a regular schedule of training, metacognitive training by the speech therapist to promote development of compensatory strategies and foster generalization to real world tasks, followed by group discussion, and supervision when using computers to access brain training games. Quantitative data analysis revealed that 2 of the 3 participants experienced modest improvement on the objective outcomes measures examining memory and attention. One participant (Participant A) experienced substantial gains on outcomes measures of memory and composite cognitive functioning, without improvement on outcomes measures of attention. The individual who experienced the greatest gains was the youngest individual with the most recent injury. This individual's improvement may be partially related to the natural recovery process; however, he clearly articulated strategies he learned over the course of training that improved the efficiency and effectiveness of his memory and attention. Each of the participants enjoyed the opportunity to engage their brains in purposeful activity, which was subjectively beneficial. Despite Clay and Hopps (2003) findings of non-adherence to rigid regimens, participants in this study found the routine of twice weekly training sessions to be beneficial and effective.

These participants experienced intermittent technical difficulties when attempting to train outside the twice-weekly program suggesting that a usability gap exists between computer-based brain training and individuals with brain injury. 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, 2) adequate time for navigating the keyboard to allow for cognitive and physical limitations, and 3) the ability to terminate games that are beyond the participant's abilities and move on to other games. Establishing a pricing structure that takes into account the financial limitations of individuals on fixed incomes will be important.

5. CONCLUSIONS

Rehabilitation research conducted in treatment settings poses challenges unlike those of grant-supported research conducted by academics and professional researchers. Self- or unit-directed research is limited by insurance reimbursements, lack of clinician time, and self- or unit-directed research may not be generalizable to other patients (Wilson and McLelland, 1997). Nevertheless, without the knowledge provided by such research, it is difficult to assess the effectiveness of clinical practice. The initial results from the 3 participants in this study reveal that individuals with acquired brain injury may need the structure and support of a professionally staffed and supported program to benefit from commercially available brain-training games, consistent with the findings of Cicerone et al. (2010). While each of the participants was interested and engaged in the brain training games, designing a product that is commercially viable for a wide ranging audience, including individuals with cognitive and physical limitations, is difficult. The task demands of training suitable for an adult with acquired brain injury involving physical and cognitive deficits are different from training suitable for a young adult seeking to maximize cognitive functioning. The availability of web based training for cognitive recovery following brain injury offers tremendous potential for cognitive rehabilitation, as long as the necessary supports are in place.

Acknowledgements: This research was supported by Lumos Labs, 153 Kearny Street, San Francisco, CA, 94108 and Dignity Health Sierra Nevada Memorial Hospital, 155 Glasson Way, Grass Valley, CA 95945.

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A serious-gaming alternative to pen-and-paper cognitive scoring – a pilot study

G House[1], G Burdea[1], K Polistico[1], J Ross[2], M Leibick[2]

[1]Bright Cloud International Corp,
Highland Park, New Jersey, USA

[2]Memory Enhancement Center of America, Inc.
Eatontown, New Jersey, USA

[1]*{cto, president, kpolistico}@brightcloudint.com*, [2]*{jrossmd, mleibick}@memorycenternj.com*

[1]*www.brightcloudint.com*, [2]*www.memorycenternj.com*

ABSTRACT

The majority of cognitive virtual reality (VR) applications have been for therapy, not cognitive stratification/scoring. This paper describes the BrightScreener™ and its first pilot feasibility study for evaluating elderly with various degrees of cognitive impairment. BrightScreener is a portable (laptop-based) serious-gaming system which incorporates a bimanual game interface for more ecological interaction with virtual worlds. A pilot study was undertaken to determine if BrightScreener is able to differentiate levels of cognitive impairment based on game performance, as well as to evaluate the technology acceptance by the target population. 11 elderly subjects were recruited by the Clinical Coordinator at the Memory Enhancement Center of America (MECA, Eatontown, NJ) site. They had an average age of 73.6 years, and averaged 14.5 years of education. Subjects first underwent clinical scoring with the standardised Mini Mental State Exam (MMSE). During the same visit they underwent a familiarization session and then an evaluation session on the BrightScreener. At the end of their visit, each subject filled a subjective evaluation exit form. Technologists were blinded to MMSE scores. Subsequent group analysis of the Pearson correlation coefficient showed a high degree of correlation between the subjects' MMSE scores and their Composite Game Scores (0.90, $|P| < 0.01$). Despite the small sample size, results suggest that serious-gaming strategies can be used as a digital technique to stratify levels of Cognitive Impairment. This may be an alternative to conventional standardised scoring for Mild Cognitive Impairment and Dementia.

1. INTRODUCTION

According to the Alzheimer's Association (2013), more than 5 Million Americans are suffering from the ravages of this irreversible neurodegenerative disorder. Alzheimer's is a disease with unknown causes, and no effective treatment to slow its relentless progression. As a consequence 1 in 3 seniors die from complications related to dementia, becoming the 6^{th} leading cause of death in United States.

Equally important to the large number of seniors affected, is the impact this degenerative cognitive disorder has on society. The same report cited above estimates the value of caregiver care at more than 200 Billion dollars annually. With the aging of America this situation will only worsen, having been called the "Grey Tsunami." It is estimated that 13.8 million Americans will have Alzheimer's by 2050, with an associated staggering cost of 1.2 trillion dollars (Hebert et al, 2001).

The National Institute for the Aging (part of NIH) had issued new guidelines regarding the diagnosis of cognitive disorders related to Alzheimer's (McKhann et al, 2011). These guidelines outline the progression of cognitive decline from pre-clinical phase, to Mild Cognitive Impairment (MCI), and finally dementia due to Alzheimer's Disease. The pre-clinical phase is a newly defined stage of the disease reflecting current evidence that measureable biomarker changes in the brain may occur years before symptoms affecting memory, thinking, or behaviour can be detected. In the window of 5 years or more prior to any symptoms, individuals at risk of progressing to full blown dementia should receive special monitoring and early intervention. Unfortunately, this is not typically the case in current standard of care.

In the second phase (MCI) mild changes in memory and thinking are noticeable and can be measured on mental status tests, but are not severe enough to disrupt a person's day-to-day life. Finally, with the progression to dementia due to AD, areas of thinking, memory and behaviour are moderately to severely affected.

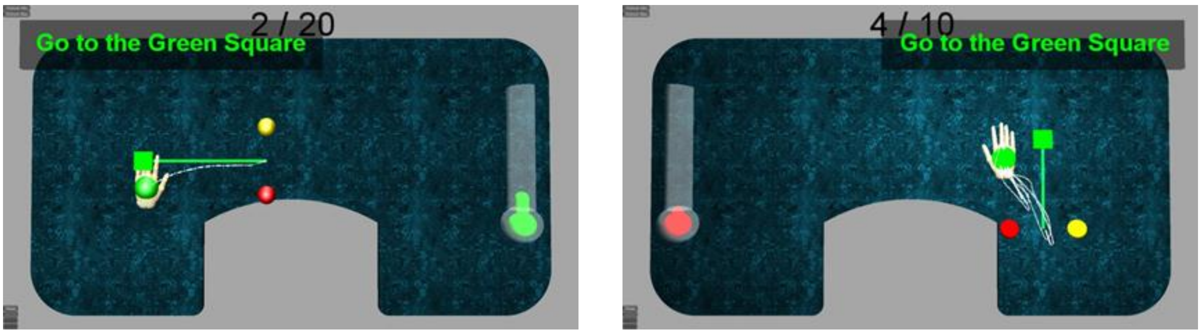
Early screening of an aging America is typically done using the Mini Mental State Exam (MMSE) (Rosenzweig, 2010) or the Clinical Dementia Rating (CDR) questionnaire (O'Bryant et al, 2010), both paper-based tests. MMSE takes 15 minutes to administer, and involves the tester and the patient. It does not however capture indirect information related to the subject's social life, independence in daily activities, hobbies, all of which could shed light on the subject's possible cognitive impairments. CDR is more involved, incorporating the input of the caregiver/spouse and takes about 50 minutes to administer. It is more precise than the MMSE, because it captures information from additional areas. Still, there is strong agreement between the two instruments for general categorization of impacted individuals as mild, moderate or severe (Perneczky, 2006). However, administering both of these cognitive tests to a large number of subjects becomes impractical with current methods due to associated cost and scarcity of qualified practitioners.

What is needed is a portable system that can be placed in primary care physician's office, and performs a quick screening for MCI with minimal human assistance (which reduces the costs and a source of variability). This would allow treatment to be applied earlier, with a higher chance of slowing down the disease progression. To further reduce care costs and increase access, such system should be a computerized platform with both cognitive testing and therapy functions, as well as the ability to present data remotely.

In an early review of cognitive evaluation technology (Wild et al, 2008) it was found that computerized cognitive testing systems offer advantages in standardization of administration and stimulus presentation, accurate measures of response latencies, automated comparison in real-time with an individual's prior performance and reduction of testing cost. However while these systems address the basic indices of psychometric properties, their variability in available computerized test batteries requires case-by-case analysis.

In 2010 Bright Cloud International (BCI) developed the *BrightArm*^{TM}, a robotic table for integrative rehabilitation of elderly stroke survivors (Rabin et al, 2012). The next year the company experimented with three dementia ward residents who had also motor involvement due to upper extremity fractures (Burdea et al, 2013*a*). Of the three subjects, two had intact working memory, and one was in an advanced stage of Alzheimer's and had lost her working memory. Figure 1 shows side-by-side the same Pick-and-Place game played by a subject with intact working memory (left) and the Alzheimer's subject (right). Her difficulty in remembering what to do, once she had picked up the ball is visualized by the winding trace of her arm movement on the BrightArm table. This led BCI to the idea that serious games have a cognitive impairment scoring function.

Section 2 describes *BrightScreener*, a laptop-based system being developed by BCI to provide integrative cognitive scoring using bimanual interaction with custom VR games. Section 3 presents results from its first pilot trial on elderly subjects with various degree of cognitive function. These results are discussed in Section 4, and compared with other studies involving computerized systems used on MCI and dementia subjects. Concluding remarks are given in Section 5.



(a) *(b)*

Figure 1. *BrightArm training of residents in a dementia ward: (a) subject with intact working memory;(b) subject with no working memory due to Alzheimer's disease (Burdea et al, 2013a). ©Bright Cloud International. Reprinted by permission.*

2. METHODS

2.1 Experimental system

Unlike the BrightArm, BrightScreener is laptop-based, and portable. As seen in Figure 2, the new system hardware incorporates a Razer Hydra bimanual game interface (Sixense, 2011), allowing the subject to interact with the custom simulations. The Hydra pendants are light, intuitive to use and track full arm movements in real time. In addition they measure the degree of index flexion-extension, which combined with the tracking feature allow the creation of dual tasking scenarios.

2.2 Games used for cognitive scoring

The BrightScreener software is comprised of several games that were ported from BrightArm and re-written in Unity 3D (Unity Technologies 2012). Unity 3D is better documented than Java 3D used in the earlier BrightArm system. Furthermore, all games were made to have uni-manual and bimanual modes, with game avatars controlled through the Hydra pendants. Four of the games were selected for the BrightScreener cognitive evaluation feature. These games were *Breakout 3D*, *Card Island*, *Tower of Hanoi 3D* and *Pick-and-Place*.

Breakout 3D (Figure 3*a*) asked subjects to bounce balls alternating between right and left peddle avatars, so to destroy rows of crates placed on an island. The game tested executive function through reaction time (processing speed) and task sequencing, as well as attention.

Card Island (Figure 3*b*) asked subjects to pair cards arrayed face down on the sand. Hand avatars were used to select and turn cards face up (two at-a-time) when the pendant trigger button was pressed. The placement of the game on an island integrated the sound of waves, so to further relax the subjects. The Card Island game tested short-term visual memory and attention.

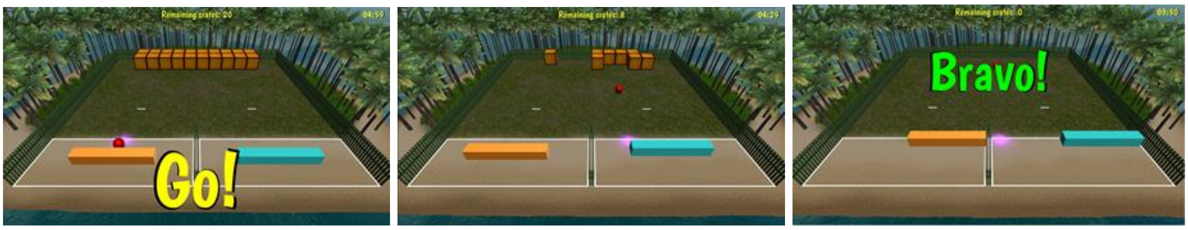
Tower of Hanoi 3D (Figure 3*c*) is BCI version of a well-known cognitive game, normally played with a mouse. The subject was asked to restack disks of varying diameters from one pole to another pole, using the third pole as way-point. The complexity of the task stemmed from the requirement that a larger disk may never be placed on top of a smaller one. A disk was picked up by overlapping it with a hand avatar and squeezing the trigger to flex the hand fingers. In bimanual mode there were two hands, one colored green and one red, and disks were similarly colored. Each hand avatar could only manipulate like-colored disks. The game tested executive function (task sequencing and problem solving).

Finally, in *Pick and Place* (Figure 3*d*) the subject had to pick up a ball, from several available, and place it on a like-colored target square. While en route to the target the movement of the hand avatar was traced. The game tested working memory and divided attention when played in bimanual mode.

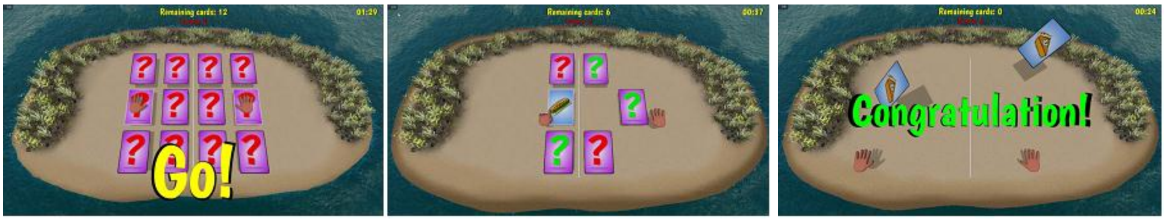
Each game had four levels of difficulty, with the most basic setting utilizing one hand controller (uni-manual mode). The remaining three levels required both hand controllers to play (bimanual mode). At successive levels, *Breakout 3D* becomes more difficult with increase in the speed of the ball and decrease in the size of the paddle avatars used to bounce it. *Card Island* became more complex by increasing the number of cards to be paired with each level. Similarly, the number of disks in *Towers of Hanoi 3D* increased with successive difficulty levels (two disks, then three, then four disks). *Pick and Place* increased difficulty with the increase in number of targets and the removal of visual cues used by subjects to match ball and target colors and complete the pick and place task.

(a) *(b)*

Figure 2. *The BrightScreener™ system: (a) game interface;(b) subject during training (Burdea et al, 2014). © Bright Cloud International. Reprinted by permission.*



(a)



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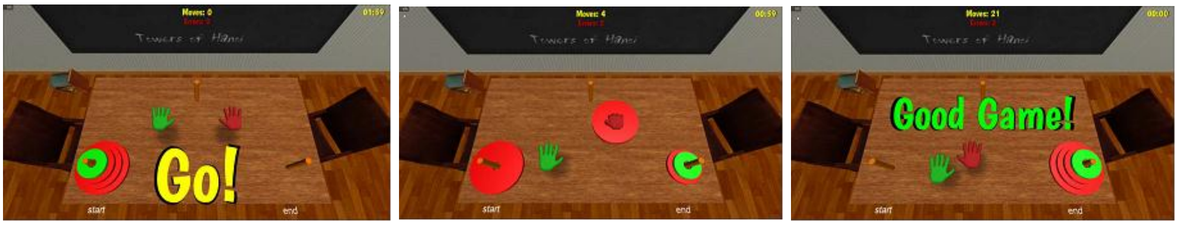

(c)

(d)

Figure 3. *BrightScreener testing games: (a) Breakout 3D;(b) Card Island; (c) Tower of Hanoi; (d) Pick-and-Place (Burdea et al, 2013b). © Bright Cloud International. Reprinted by permission.*

2.3 *Game scoring Algorithms*

The scoring algorithms for *Breakout 3D*, *Card Island*, and *Pick and Place* have been detailed previously (Burdea et al, 2014). The scoring equation for each game incorporates both difficulty and performance metrics. For example, there is a 25% bonus in difficulty for playing bimanually over the uni-manual version of the same game. Play time is typically used to rate game performance. The score formula for *Tower of Hanoi 3D* is:

$$Score = \frac{\left(If\ bimanual\ 1.25;\ else\ 1.0\right) * \left(Minimum\ \#\ of\ Moves\right) * 100}{Log\left(Time\ in\ Seconds\right) * \left(Actual\ \#\ of\ Moves + \#\ of\ Dropped\ Disks\right)} \tag{1}$$

In the numerator, level of difficulty is quantified by whether the game is played in bimanual mode (25% bonus) and minimum number of moves needed to complete the game. Restacking 2 disks required a minimum of 3 moves, 7 moves were necessary to restack 3 disks and 15 moves for 4 disks. In the denominator, game performance is quantified by the logarithm of play time and the actual number of moves taken to complete the game combined with the number of disks dropped en route to the poles. Longer length of game play (measured by time and number of steps) corresponds to lower performance and hence has a lower game score.

2.3 *Study design*

The sequence of steps used in this study consisted of (1) subject consenting, (2) a tutorial session on the BrightScreener, followed by (3) standardised cognitive testing, then (4) the game-based testing session and (5) an exit questionnaire. Each subject completed the study in the span of a few hours (depending on their cognitive functioning level). The study was approved by the Western Institutional Review Board and took place during two days at the Memory Enhancement Center of America – MECA (Eatontown, NJ) in February 2014.

2.3.1 Participants characteristics. Eleven subjects were recruited by the study Clinical Coordinator, from the pool of potential participants at MECA. Of these five were women and six men. Subjects 1-5 were tested the first Saturday and Subjects 6 –11 were tested a week later. The group had an average age of 73.6 years, with a range from 61 to 90 years old and a standard deviation of 8.6 years. The mean education level was 14.5 years in school, with a standard deviation of 4.2 years.

2.3.2 Tutorial and testing session composition. Since subjects were new to BrightScreener, it was necessary to have a tutorial session before the actual cognitive evaluation session. During the tutorial session subjects played the four games previously described, and each game was played at progressively harder levels of difficulty. The subjects cycled through all four games at the most basic level of difficulty before progressing to the next level of each game type, and so on. The tutorial session lasted about 35 minutes per subject.

For testing, the subjects completed the four levels of difficulty of a given game before proceeding to the next game, and so on. The evaluation session lasted about 30 minutes per subjects.

Table 1. *Subjects' characteristics (gender, age, education level).*
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Subject	Sex	Age	Years in school
1	M	64	16
2	M	73	19
3	M	82	22
4	F	90	14
5	M	73	18
6	F	77	12
7	M	78	14
8	F	70	14
9	F	61	12
10	F	64	13
11	M	78	6
Average age	73.6 (8.6)	Average School years	14.5 (4.2)

2.3.3 Data Collection Instruments. Subject's data was collected during the study using MMSE, game scores, and an exit interview. Mini Mental State Exam was used to evaluate the subject's cognitive function. The MNSE was administered by the Clinical Coordinator in a quiet room and the BCI researchers were blinded to the scores.

Subsequent to the MMSE testing, subjects were given the BrightScreener evaluation session and game scores stored transparently for each subject. Finally, the subjects filled a subjective evaluation exit form in the Clinical Coordinator room. The form had 8 questions scored on a Likert scale from 1 (least desirable outcome) to 5 (most desirable one). The questions were: "Were instructions easy to understand?," "Were the games easy to play?," "Were the game handles difficult to use?," "How easy was playing with one hand?," "How easy was playing with both hands?," "Were you tired after playing the games?," "Did you have headaches after playing the games?," and "Did you like the system overall?"

3. OUTCOMES

3.1 MMSE scores

Table 2 lists the MMSE scores of the 11 study subjects. These scores ranged from a low of 9 to a high of 29 (out of a maximum of 30). The average MMSE score was 23.9 with a standard deviation of 5.4. Based on their MMSE scores, participants were ranked by degree of cognitive impairment from 1 (the least) to 11 (the most). Subjects with identical scores (1 and 6, 2 and 8) were given the same rank (1 or 7, respectively).

The MMSE scores may be used to determine the degree of cognitive impairment (Folstein, 2001). Three of the subjects were classified as having normal cognitive function, seven of the subjects were diagnosed with Mild Cognitive Impairment (MCI) and one with Severe Cognitive Impairment (Alzheimer's). For control, at least one participant that was expected to have a normal diagnosis was included in each day of the study. However, the identities of these individuals were not known by technologists conducting the game training and testing sessions.

3.2 Testing session game score-based ranking

Table 3 summarizes the game scores and corresponding ranking during the testing session. For each of the 4 games played the score assigned was the average score for four difficulty levels of each game. Participant 4 consistently scored the lowest across games, however the participant with the highest score varied between games. In order to realize an overall ranking, each participant's scores were averaged into a Composite Score. Subject 4 had the lowest composite score (5.9) and Subject 5 the highest composite score (61.3).

Subsequently the 11 subjects were ranked from 1 to 11 using the composite game scores. The scores were also categorized into four basic bands following degree of cognitive impairment: normal, mild, moderate, and severe. The thresholds quantizing composite scores to the cognitive impairment levels were calibrated based on the fact that the Clinical Coordinator indicated prior to study that two undisclosed participants were expected to have a normal cognitive state. As seen in Table 3, eight of the participants were categorized as MCI, none of the participants were classified as having moderate cognitive impairment and one participant was categorized has having severe cognitive impairment. This is consistent with the distribution of the MMSE, although individual classifications do vary (i.e. participants 2 and 6).

Table 2. *Subjects' MMSE scores and cognitive impairment levels.*
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Subject	MMSE Score	MMSE Rank	Cognitive impairment level
1	29	1	Normal
2	24	7	Mild
3	25	5	Mild
4	9	11	Severe
5	27	3	Normal
6	29	1	Normal
7	26	4	Mild
8	24	7	Mild
9	23	9	Mild
10	25	5	Mild
11	22	10	Mild

3.3 MMSE score correlation to serious games score

Table 4 shows the Spearman correlation (Laerd, 2013) between individual game scores and the MMSE test scores. The correlation values ranged from a low of 0.6 for *Breakout 3D* to a high of 0.85 for *Tower of Hanoi 3D*, with probability $|P| < 0.05$. As seen, the correlation for *Breakout 3D* was less than for the other games due to the fact that Subject 11 performed particularly well for this game. When Subject 11 was removed from the correlation computation, the *Breakout 3D* correlation increased to 0.75. This correlation value is now in line with *Card Island* and *Pick and Place* correlation values.

The Composite Score correlated to MMSE outcomes better than individual game scores. The correlation value was 0.90 with a confidence $|P| < 0.01$. This is reflective of the nature of the individual games, each targeting a different group of cognitive domains. The rationale for using the Composite Score is a broader spectrum of domains may be captured in a single value, similar to the methodology of the MMSE instrument.

The Spearman correlation was subsequently computed between the ranking of subjects using MMSE scores and the ranking of those same subjects based on game scores. The ranking using the composite score had a correlation value of 0.6 and $|P|<0.05$. The Spearman value was higher when ranking by *Tower of Hanoi 3D* alone with a correlation of 0.69 with $|P|<0.05$. A better Spearman correlation was achieved by limiting the contribution of *Pick & Place*, correlation value of 0.71 with $|P|<0.05$.

Table 3. *Subject's game scores and corresponding ranking.*
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Subject	Breakout Score	Card Island Score	Pick & Place Score	Towers Score	**Composite Score**	Composite Rank	Cognitive impairment level
1	78.8	43.3	37.1	74.3	**58.4**	3	MCI
2	51.9	49.9	52.0	86.9	**60.2**	2	Normal
3	64.7	53.5	36.9	70.5	**56.4**	5	MCI
4	18.3	5.4	0.0	0.0	**5.9**	11	Severe
5	69.9	53.6	46.1	75.5	**61.3**	1	Normal
6	39.7	41.0	36.1	76.8	**48.4**	8	MCI
7	56.1	56.8	38.9	77.6	**57.3**	4	MCI
8	46.7	49.6	32.5	55.6	**46.1**	9	MCI
9	58.6	57.6	42.4	57.9	**54.1**	7	MCI
10	61.2	60.8	23.5	71.6	**54.3**	6	MCI
11	83.4	26.8	26.6	20.4	**39.3**	10	MCI

Table 4. *Subjects' game scores correlation to their MMSE scores.*
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	Breakout 3D	Card Island	Pick & Place	Tower of Hanoi	Composite Score
Correlation	0.60	0.75	0.78	0.85	**0.90**
P	0.045	0.006	0.0037	0.00048	**0.00008**

Spearman rank correlation tends to amplify noise in the ordering. This is seen through the fact that the overall correlation value of 0.6 is much lower than the 0.9 found by correlation between composite game scores and MMSE scores. If BrightScreener were to be used as a cognitive function scoring tool, it may be sufficient to categorize subjects into 4 general categories (normal, Mild, Moderate and Severe cognitive impairments), as opposed to get exact ordering within particular categories. To this end, the cognitive impairment levels for games scores was correlated with the diagnostic from MMSE test. Here, a much higher correlation value of 0.8 was measured, with a $|P| < 0.01$.

3.4 Subjective evaluation outcomes

The subjects were asked to fill out a subjective questionnaire after completing the game-base testing. Although anecdotal evidence suggested that the subjects rarely played video games, the subjective evaluation response was consistently positive. For example, subjects gave an average rating of 4.8 to the question "Were the instructions easy to understand?"

The challenge of playing bimanually was measured through the question: "How easy was playing with both hands?" This received the lowest rating of all questions, namely a 4.1 out 5. Finally, the subjects were asked "Did you like the system overall." Each of the 11 participants gave the system a perfect rating of 5. All the other questions received a rating of 4.3 to 4.8.

4. DISCUSSION

The aims of this pilot study were: 1) to determine if the BrightScreener system was able to differentiate levels of cognitive impairment based on game performance, and 2) to evaluate the technology acceptance by the target population. Virtual reality use in emotive therapy has been tried successfully for a number of years, beginning in the 90s (Rothbaum et al, 1999). Within the cognitive domain many studies have used virtual supermarkets to train executive function (Lee et al, 2003), or as a more ecological method for MCI diagnosis (Werner et al, 2009). Researchers tested a group of 30 MCI patients and 30 healthy elderly adults. They observed significant differences in the performance of the two groups in the virtual supermarket simulation. A key differentiation with the prior systems is that BrightScreener uses serious-games as a scoring method for cognitive impairment. The results were shown to be consistent with determination of a popular pencil and paper screening method (MMSE).

BrightScreener interactions were mediated by a bimanual game controller, and the technology was well accepted by the subjects. Another usability study involving an off-the-shelf game interface used the Wii controller with dementia patients (Boulay et al, 2011). Similar to the present study, researchers found that subjects were able to use the Wii and liked the technology very much.

It is important to note that, while the BrightScreener game scores and composite scores correlated well with the subjects' MMSE scores, there is room for improvement. Specifically, the areas of language processing and problem solving, while present in the MMSE tests, were missing to a large extent from the BrightScreener games. It is possible that with more games covering these areas, the overall correlation could improve further.

The number and composition of the subject group also played a role in the feasibility study outcome. The level of cognitive function of the 11 subjects was such that Moderately Impaired subjects were missing from the sample. Furthermore, the sample was small, with implications on the statistical power of the study findings. Further studies are needed to determine if the same correlations exist for a larger sample, and/or for different patient populations.

5. CONCLUSIONS

This paper presented the BrightScreener portable digital system. A pilot study evaluated its ability to score Cognitive Impairment of adults based on game performance. To the author's knowledge this is the first study of a bimanual game library for use in cognitive evaluation. Bright Cloud International believes that the full potential of BrightScreener will be realized when acting as a dual platform for cognitive scoring and for rehabilitation. With greater adoption of BrightScreener in clinical practice, longitudinal studies may be possible, with subjects unaware that they are periodically evaluated, possibly at a distance. For dementia populations, the hope is that focussing on a pleasant and non-threatening activity that engages thinking may prove to be successful in delaying the onset of Alzheimer's Disease.

Acknowledgements: Research reported here was supported in part by grant 9R44AG044639-02A1 from the National Institute for the Aging (NIH) and by Bright Cloud International Corp.

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Differences in effects when using virtual reality balance trainer or wobble board in terms of postural responses

I Cikajlo, S Bajuk

University Rehabilitation Institute,
Linhartova 51, Ljubljana, SLOVENIA

imre.cikajlo@ir-rs.si

www.uri-soca.si

ABSTRACT

The aim of this study was is twofold: firsts to examine whether the choice of balance training device has any influence on overall therapeutic outcome and secondly whether it affects postural strategy in patients with low-back pain. Six patients used Gamma trainer with virtual reality games and five patients used a wobble board. Before and after the treatment the postural responses were tested. 5 out of 11 patients improved their postural responses in terms of latency and stability. Contribution of the balance training to the improvement of postural responses was not statistically significant (ANOVA, $p > 0.05$), but differences in functional reaching test were statistically significant ($p = 0.0215$) for each group ($p = 0.0419$), while differences between the groups were not found significant ($p = 0.1257$). In spite of small number of participating subjects, we may suggest that balance training improves postural responses and functional reaching in people with low back pain regardless of the choice of the balance training device.

1. INTRODUCTION

Chronic low-back pain is one of the most common causes of absence from work in the EU, U.S. and elsewhere in the world (Blasche et al, 2013). In subjects with acute and chronic low-back pain a change in the activation of certain muscle groups appear, in particular of the trunk muscles. A delay in the activation of trunk muscles can be considered as an impairment of the neuromotor control of spinal stabilization system. This actually leads to the changes in the behaviour of the trunk muscles. These muscles provide stability and control of the stiffness of the spine when compensating for internal and external forces generated by the movement of the entire body. Hodges (Hodges et al, 1998) has shown that the co-ordination of the trunk muscles correlated with the movement of the lower limbs in all subjects, those w/o low-back pain. The published results showed latencies in the electromyographic activity of certain abdominal muscles for movement of the lower limbs as a result of (un)expected perturbations in all directions in people with low-back pain.

Therefore rehabilitation is recommended not only in the chronic phase, but also in the sub-acute, when usually the healthcare professionals recommend resting. Particularly balance training that also activates trunk muscles is recommended. Indeed, balance training has proven to be more effective than individual muscles strengthening (Blasche et al, 2013). However, the exercises should be target based, repeatable and be conducted for two consecutive weeks.

In the study we were particularly interested in the implications of balance training on postural responses in persons with low-back pain as reported on latencies of responses in selected directions of perturbations. We also investigated whether the functional progress in rehabilitation depends on the method and device chosen for balance training.

2. METHODOLOGY

2.1 Balance training equipment

The Gamma trainer (PHU Technomex Sp., Gliwice, Poland) is a simple platform for evaluation and neuromuscular coordination training, weight transfer and balance training. It is designed as a pressure platform with two plates, each measuring the vertical component of the reaction force with four sensors and calculates the centre of the reaction force. These two measures enable calculus of the common centre of gravity (COG).

Besides COG a linear acceleration and speed of the COG can be also calculated. Games presented in a virtual environment to attract attention, enabling a variety of settings, thus promoting neuromuscular coordination, reflex movements, etc. The user interacts with the game through the COG tracking. For the case of loss of balance lateral handles were available, but to prevent a fall a physiotherapist who monitors the whole process, was also present (Fig 1a). The wobble board (diameter 41/9 cm, max tilt 22^o) is designed as a rehabilitation tool for balance training, muscle strengthening and concentration. The disc is designed as a movable surface, which requires rather good balance of the user. Due to the low-back pain or neuromuscular disorders or diseases such balancing required full time assistance of the physiotherapist (Fig. 1b).

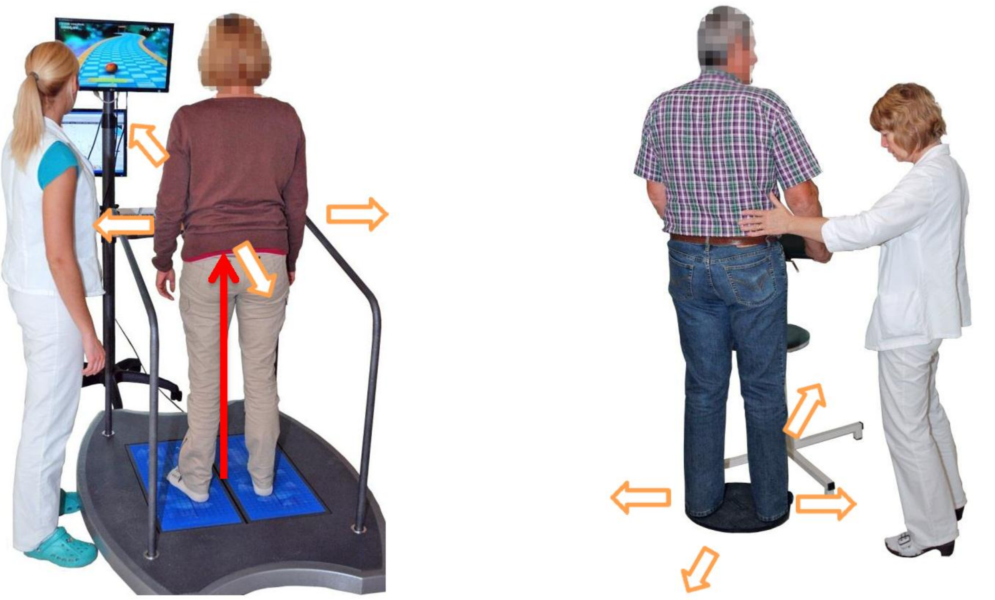

Figure 1. ***a)*** The *Gamma device consists of two pressure plates, which monitor the movement of the vertical component of the gravity force. The appropriate information is then displayed in the form of a moving object in a virtual environment.* ***b)*** *On the wobble board besides balance skills additional muscle strength is required. And in subjects with low-back pain or balance disorders also an assistance of a physiotherapist is mandatory.*

2.2 Subjects

In the study 13 outpatient volunteers participated (3 men, 8 women, mean height 167.82 ± 8.23 cm, mean age 56.81 ± 12.36 years, mean weight 72.73 ± 19.51 kg, right-handed) and 11 of them also completed the clinical and the assessment protocol. The inclusion criteria were: chronic low-back pain expanding into the lower limb with the possibility of malfunction thoracic spinal roots, which does not cause paresis of muscles of the lower limbs. Exclusion criteria were as follows: 1) a variety of joint injuries in the lower limbs (hip, knee, ankles), causing an additional pain and disruption of passive or active joint mobility, 2) various traumatic situation in the lower extremities, causing abnormalities in the lower limbs, 3) associated impairments or diseases of the central nervous system, 4) peripheral or central paresis of the lower limbs muscles. 6 patients out of 11 were randomly selected for balance training on Gamma device (group G), and the remaining 5 patients were set for the wobble board (group W) balance training.

2.3 Equipment for postural responses assessment

A modified device BalanceTrainer (Fig. 2) equipped with four electric motors was used to capture postural responses after the perturbation at the level of pelvis. The motors were computer controlled via an interface (National Instruments PCI - 6229, USA), instrumented with suitable electronic circuits and high-speed automatic thermal fuses, which ensure 100% safety, despite the low level voltage supply of 24V from batteries (Cikajlo and Matjačič, 2009) was used. Mechanical constraints of the device provide a safe standing frame tilt in all directions of the transverse plane (Fig. 2b) and prevent a fall of the person standing in the frame.

The computerized system generated an electrical pulse (duration 600 ms) after the operator (physiotherapist) pressed the button, which activated the electric motor and caused a sudden mechanical tweak of the standing frame in a randomly selected direction. The computer randomly selected one of the 4 main directions (forward -

FW right - RT , left - LT and back - BW) or a combinations of them (forward / right - FR , back / right - BR , forward / reverse - FL, back / left - BL). The onset of the mechanical tweak or perturbation was also randomly selected, within 1s after the activation in the user interface and the magnitude of displacement was approximately 10 cm. Thus we ensured the assessment environment where the subject could not predict the direction or the accurate onset of the perturbation. The participating subjects positioned in the standing frame stood on the force plate, which measured the changes in the COG (Cikajlo and Matjačić, 2009). Instead of the 6 degrees of freedom tensiometric force plate, we used a simple force plate with four pressure sensors measuring only the vertical component of the reaction force (Wii Balance Board, Nintendo, USA). We calculated a common vertical reaction force, COG using the data of four pressure sensors and compared the outcomes with the normative assessed in healthy subjects (Cikajlo and Matjačić, 2009). The complete measurement lasted 6s, thus the complete postural response was assessed as well as potential problems in the “recovery” after the response.

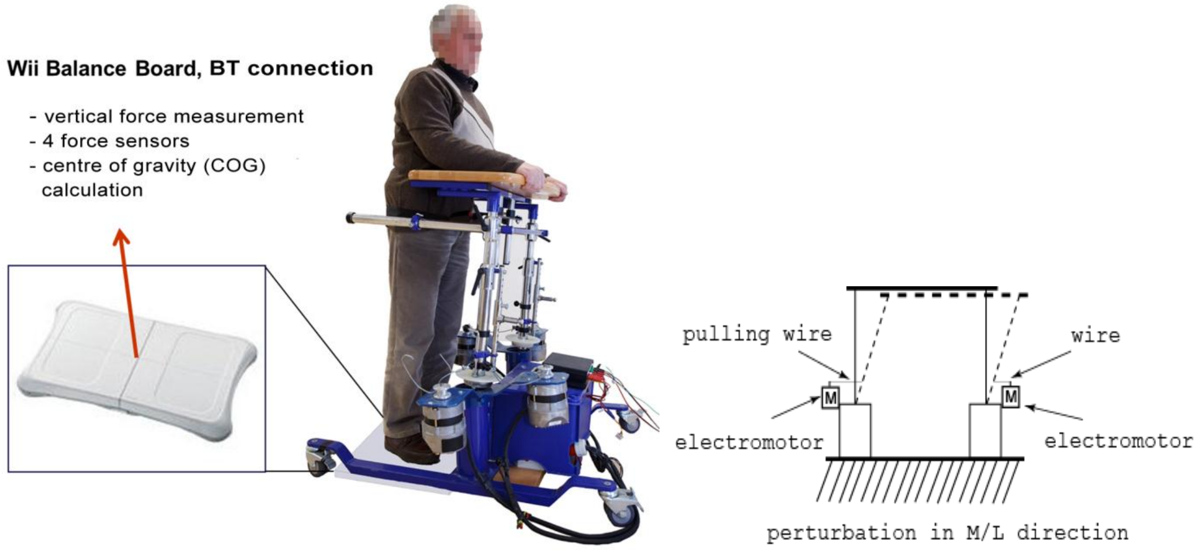

Figure 2. ***a)*** *Postural perturbation generation and response assessment device was based on the generation of mechanical tweak in the level of pelvis in 8 directions of transversal plane. Deviation of the COG was measured by simple force plate (Nintendo Wii Balance Board). A force plate was connected to the measurement system via bluetooth (BT) connection.* ***b)*** *The device forces a mechanical disturbance in the medio-lateral (M / L) direction at the level of pelvis. The person in the device responds to the disturbance of postural response to prevent a fall.*

2.4 *Protocol of the study*

Targeted therapy lasted 14 days (5 consecutive days / week) and comprised of hydrotherapy, individually guided exercises in relation to the pathology and treatment of the pain with functional electrical stimulation and balance training. The therapy was common to all subjects, while subjects performed balance training in two separate groups. Subjects assigned to balance training with the device Gamma (G) performed training in the following chronological order: 5 minutes of training, 5 minutes of passive rest and 5 minutes of training with the same task in a virtual environment.

Balance training with the Gamma device consisted of two tasks in a graphical computing environment, two games. The first task requested from subjects to sort the objects by shifting the weight and thus the centre of gravity to the left (right) or front (back). In the second task the user rolled the ball on a selected virtual path. The direction of the ball was determined by shifting the weight (COG) left-right and the speed was pre-set by the physiotherapist.

Subjects performing balance training on wobble board (W) followed the same daily schedule: 5 minutes of balance training on the board (weight transfer in the A/P and M/L direction), 5 minutes of passive rest and repeat the balance training for additional 5 minutes.

Prior to, and after the therapy postural response assessment and some clinical tests (functional reaching, standing on the left and right leg) were carried out. Functional reaching (FD) is an assessment test where the subject is trying to reach the maximal distance with hands during the statically stable stance (Duncan et al, 1990). We carried out 3 assessments for each directions of perturbation (FW, BW, LT, RT, BR, BL, FR, and FL).

2.5 *Evaluation of postural responses and clinical tests*

The postural responses were analysed with special postural response analysis tool (Cikajlo and Matjačić, 2006). The assessed COG postural responses were analyses for each direction of perturbation. Each response was compared with a normative data (Cikajlo and Matjačić, 2009, Winter, 2009) in terms of amplitude overshoot and latency. If the overshoot or latency was within 2 standard deviations of the normative, the response had been considered acceptable. Otherwise, each unacceptable response was carefully examined and major changes were highlighted. Slow reaction of the patient (large latency) or with a large overshoot (more than 2 standard deviations) implies a high degree of instability in the response.

Additionally we also statistically tested the outcomes of the clinical tests before and after therapy. Mean and standard deviation for each group of subjects (G, W) and Analysis of Variance was conducted to see whether the differences in performance measures for each study condition were statistically significant (Statistical Toolbox, ANOVA -2, Matlab, MathWorks Ltd., Natick, USA).

3. RESULTS

In 2 subjects from different groups (W, G) we did not find any deviations from the postural responses normative (Cikajlo and Matjačić, 2009) and/or minor deviations were limited to one direction and this remained unchanged after therapy. In three other subjects, we found minor problems (oscillation response, increased response amplitude in the wrong direction, delayed response) in postural responses to the perturbations in those directions in which responses from non-dominant limb were expected (directions of perturbation: FL, BL, LT and partly BW). In these three subjects there was minor progress after treatment (Fig. 3), especially the response in the AP direction became stable without a delay and matched the normative. The Fast Fourier Transform (FFT) peaks appear at lower frequencies in AP direction and vertical force, however, peak at higher frequencies in ML directions means more oscillations and a delayed response. However, the rest of the subjects (3 from G and 3 from W group) reduced the latencies of the responses for perturbation directions LT, BL and their postural responses amplitudes in AP direction for perturbation directions FL and BL became more compliant with the normative, but only for group G (Fig 4).

The clinical outcomes revealed improvement of subjects' functional capabilities; FD increased from 20.2 (SD 9.6) cm to 26.0 (SD 7.5) cm for W and from 30.5 (SD 4.4) cm at 32.0 (SD 4.6) inches for group G after the therapy (Table 1). The ability to stand on the left (non-dominant) leg increased from 18.8 (SD 23.7) s to 22.7 (SD 22.3) for group W and from 20.8 (SD 18.1) s to 21.7 (SD 20.5) s for group G. The ability to stand on the right (dominant) leg increased from 11.4 (SD 15.6) to 18.0 (SD 5.2) for group W and from 21.8 (SD 22.0) to 24.2 (SD 21.2) for group G. The 2 -way ANOVA found no differences between participant groups in standing on the single extremity were statistically insignificant ($p > 0.05$, Table 1) and also the balance training had no significant impact on standing on a single extremity. The differences between groups W and G in functional reaching were statistically significant ($p = 0.0419$) and this may confirm the effectiveness of the therapy ($p = 0.0215$). However, interaction between the two groups before and after treatment was not statistical significant ($p = 0.1257$).

Table 1. *Clinical outcomes (mean and standard deviation).*

	GROUP	ASSESSMENT				P group effect	P time effect	P interaction
		1	STD	2	STD			
FUNCTIONAL REACHING (cm)	W	20.2	9.6	26.0	7.5	**0.0419**	**0.0215**	0.1257
	G	30.5	4.4	32.0	4.6			
STANDING ON THE LEFT LEG (s)	W	18.8	23.7	22.7	22.3	0.9441	0.5697	0.976
	G	20.8	18.1	21.7	20.5			
STANDING ON THE RIGHT LEG (s)	W	11.4	15.6	18.0	5.2	0.9724	0.1013	0.721
	G	21.8	22.0	24.2	21.2			

P < 0,05

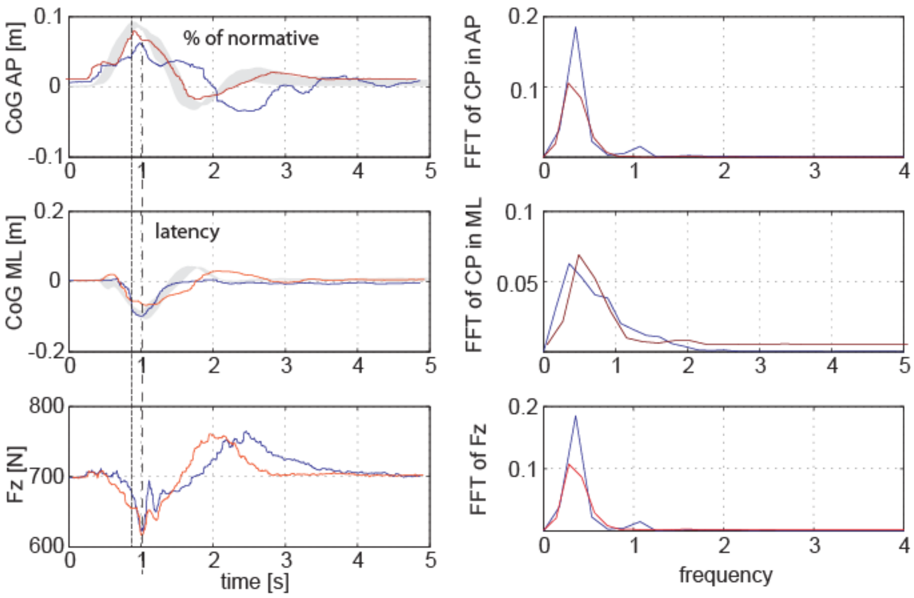

Figure 3. *Averaged postural responses (COG and vertical force F_z) in anterio-posterior (AP) and medio-lateral (ML) direction on perturbation in FL direction for the three subjects that demonstrated minor progress after the therapy (red, prior the therapy – blue, shadow area – normative). The response in AP direction became compliant with the normative. Two parameters were compared with the normative– latency and amplitude.*

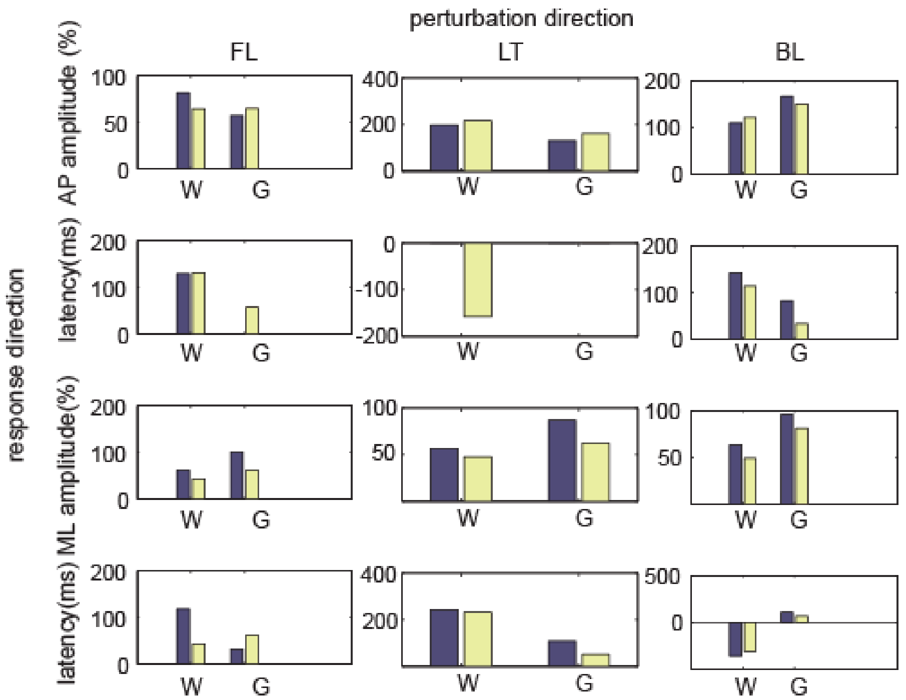

Figure 4. *Latencies and amplitude (in % of the normative) of the postural responses (COG) in anterio-posterior (AP) and medio-lateral (ML) direction on perturbation in FL, LT and BL directions for wobble group (W) and Gamma trainer group (G) before and after the therapy.*

4. DISCUSSION

Assessment and evaluation of postural responses has been considered important additional information to the clinical tests of balance, especially because it enables identification of functional problems with dynamic balance for each direction and thus presents important information in fall prediction (Cikajlo and Matjačić, 2009). The participating subjects with low back pain had minor problems with postural responses to the mechanical perturbations at the level of pelvis mainly due to the less reliable loading of the non-dominant extremity. Usually the cause of unreliability was a strong pain at the lumbar level of the spine when the non-dominant extremity was loaded. Some subjects demonstrated noticeable improvement after the therapy – the postural responses "returned" in the range of standard deviation of the normative for healthy, neurologically intact persons. Therefore we may confirm that subjects who did not experience balance disorders in spite of the low-back pain demonstrated similar postural activities than completely healthy persons (Davarian et al, 2012).

The clinical outcomes demonstrated improvement of functional capabilities in subjects with low-back pain after therapy that consisted of pain therapy with electrostimulation, hydrotherapy, individually guided exercises and balance training. Ability to stand on a single foot was shorter than in neuromuscular intact persons, which was due to the low-back pain. However, the study demonstrated improvement in quiet standing, especially in the group practicing balance with the Gamma trainer. There was no improvement in the group that practiced balance on the wobble board. Such training also had no effect on the improvement of other parameters, in particular, musculoskeletal pain after the therapy (Blasche et al, 2013). In contrast the FD test demonstrated significant improvement of functional reaching of the group W, which was also shown by the statistical test. The outcomes of the research on the effective improvement of balance ability of older people after 9 weeks (twice per week) of balance training on balance wobble board (Ogaya et al, 2011) can confirm that such balance training with the wobble board must have also contributed to the results of the FD test. Indeed the study was focused on elderly population, who were able to successfully control the movement of the COG in order to maintain the upright posture on the unstable base, such as wobble board. Similar results, demonstrating average improvement of all assessed clinical parameters, were obtained in the group that practiced balance with the Gamma device. Despite the higher FD score prior to the therapy, the subjects of the G group achieved better FD score after the therapy and balance training. The subjects were motivated and focused on a challenging racing game of the Gamma trainer, which aim was to keep the ball in the virtual path. Motivation and focusing on the task played an import role, similar as the visual feedback informing the subject about the activities within the task. The virtual environment itself cannot improve balance capabilities of the individual more or less than simple interactive tasks with visual feedback within the real environment, but can almost equally improve postural control (Lamoth et al, 2012) and has several advantages, e.g. flexibility and configurability of levels of complexity fast and without additional expenses.

5. CONCLUSIONS

Due to the small number of participating patients we may only suggest that the selected clinical outcomes and postural responses improved in patients with low back pain after the physiotherapy, which included balance training. We have demonstrated that there was no statistical difference between the balance training using the gamma device compared to balance exercises on wobble boards in terms of clinical results. Our findings are in line with expectations and the results of previous studies that found that it was difficult to distinguish which type of exercise balance would be more beneficial in rehabilitation after back pain (Desai and Marshall, 2010).

Our study found similar success of the rehabilitation outcomes with or without a system using target based therapeutic tasks in virtual reality. Such system provided extra motivation and much higher level of interest and fun (Fitzgerald et al, 2010). However, it is worth considering that wobble board training required permanent presence of the physiotherapist and thus its usefulness in patients with neurological impairment is very limited. Despite the small number of patients involved we may conclude that balance training is important for trunk muscles strengthening in people with low-back pain regardless of the choice of the balance training device. When selecting a device, the effort of the physiotherapists to ensure repeatability as well as the ability and motivation of the patients should be also considered.

Acknowledgements: The authors would like to thank all the physiotherapists for their professional contribution, especially S.Kokalj, PT and H. Jamnik, MD for helpful comments.

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Spatial working memory performance in real museum environment versus computer simulation: a comparison between healthy elderly and young adults

M Korman[1], R Kizony[2], M Hochhauser[3], T Kuflik[4], A J Wecker[5], P L Weiss[6]

[1,2,3,6]Department of Occupational Therapy, [4,5]Department of Information Systems, University of Haifa, Aba Khoushy Ave., Mount Carmel, Haifa, ISRAEL

[2]Department of Occupational Therapy, Sheba Medical Center, Tel Hashomer, ISRAEL

[1]korman.maria@gmail.com, [2]rkizony@univ.haifa.ac.il, [3]mhochh1@univ.haifa.ac.il, [4]tsvikak@is.haifa.ac.il, [5]ajwecker@gmail.com, [6]tamar@research.haifa.ac.il

ABSTRACT

In recognition of the limited ecological validity of testing in a laboratory setting, we compared spatial memory performance of healthy young and older adults in a real museum setting and on a computer simulation. In the museum, participants physically moved between display stations to locate hidden tokens; an ongoing representation of previous searches had to be remembered. A comparable task was implemented via mouse actions on a computer simulation. Nine older (60-80 years) and 20 younger (20-45 years) adults performed both tasks. The younger group was superior to the older group in terms of success and time, and all participants were more efficient within the simulated task. The feasibility of using realistic tasks in a physical location to study spatial memory is discussed.

1. INTRODUCTION

Remembering where things are, object–location memory, is essential for daily-life functioning (Postma et al, 2008). Spatial memory is a complex multidimensional process which includes a variety of components that help people to orient and act in space (Kessels et al, 2001). This cognitive process is crucial for activities such as finding your way to locations such as a supermarket and subsequently knowing where to find specific products, e.g., grocery items. Spatial memory includes the ability to remember the spatial layout of environments, to know how to travel from one place to another, to remember the locations of objects within a specific environment, to have knowledge about the spatial arrangements of objects relative to each other, and to know one's own location in the environment. Object–location memory is considered to constitute a special class of episodic memory, reflecting a form of contextual memory in which object (identity) information is bound to location information (King et al, 2004). Object–location memory appears to rely on three distinct processing mechanisms: object processing, spatial-location processing and object to location mapping (Postma et al, 2008). When spatial memory involves remembering changes in the environment, it is considered to be dynamic (i.e., spatial working memory). Postma et al. (2008) suggested that dynamic spatial memory often engages a "from within the environment" perspective (which mainly involves egocentric representations of space). The challenge of dynamic spatial memory is illustrated by what occurs when one gets lost when traveling from one place to another which requires one to relocate oneself in the environment, to update spatial knowledge about the changing environment, and to re-plan the route ahead. This involves sequences of different spatial environments as well as sequences of spatial decisions.

Conscious retrieval of object–location associations are a notable feature of the hippocampus and specific impairments of learning and memory associated with aging have been shown to be related to hippocampal damage (Postma et al, 2008). Altered synaptic plasticity in the elderly may result in changes in the dynamic interactions among cells in hippocampal networks, causing deficits in the storage and retrieval of information about the spatial organization of the environment (King et al, 2004).

It is well documented that both cognitive and motor learning abilities decline with normal aging, impeding the performance of complex cognitive skills (Salthouse, 2009; 2010). However the extent and type of these changes is variable. Declines in domains such as memory and speed of sensory processing, and deficits in attention such as the ability to sustain information processing over time, suppress irrelevant information or switch between activities have been reported (Coubard et al, 2011; Deary, 2009). Given that cognitive processes such as working memory are engaged during the early stages of motor learning (Anguera et al, 2010), age-related declines in motor behavior and learning may be due, in part, to reductions in cognitive ability.

Performance in ecological environments imposes increased perceptual and attentional loads due to the inherent sensory richness of realistic settings (Sweller, 1994). That is, the extraneous cognitive load, the load that does not contribute to the learning process itself, in real environments is usually high (Sweller et al, 1998). In diverse experimental settings it has been demonstrated that relative to young adults, the performance of older adults showed cognitive deficits when task demands increased and when high extraneous cognitive load was imposed (Lorsbach and Simpson, 1988; Van Gerven et al, 2002). Hippocampus-related memory tasks, and specifically, object-location dynamic memory tasks, have been poorly studied in ecological settings. The testing of such paradigms under realistic conditions may not only lead to novel interventions for age-related cognitive impairments, but may also contribute to an improved understanding of the mechanisms of learning and plasticity in the mature brain.

Thus, the present study aims to investigate the impact of age and environmental factors (i.e., a real museum versus computer simulation) on visual-spatial working memory of healthy older and young adults. In particular, two research questions were addressed: 1. To what extent do older adults maintain their cognitive capacity during a dynamic spatial working memory task as compared to young adults? 2. How is this capacity, measured in frequency of success, affected by performance of the task in a realistic environment where demands for a cognitive task solution are similar to a computer simulation, but differ in the extraneous task demands involving physical interaction with targets and walking around a large hall of real museum exhibits?

2. METHODS

2.1 Participants

Twenty young healthy male (9) and female (11) younger adults (M=28.5, SD=6.48 years) and 9 healthy male (3) and female (6) older adults (M=70.0, SD=5.20 years) were recruited through advertisements in the local media (university web sites, local newspaper ads and bulletin boards). Participants were excluded if they scored less than 21 points (out of a total 30) on the Montreal Cognitive Assessment (MOCA) (Nasreddine et al, 2005). They were paid ILS 70 (~$20) for partaking in the study; this amount included reimbursement for travel to the museum via public transportation.

2.2 *Instruments*

2.2.1 Assessments and Questionnaires

- *Demographic questionnaire*. The items documented participant gender, age, level of education, prior usage of simulations, etc.
- *Montreal Cognitive Assessment (MOCA).* (Nasreddine, 2005). This is a screening instrument for mild cognitive dysfunction, translated into many languages including Hebrew. It assesses different cognitive domains: attention and concentration, executive functions, memory, language, visual-constructional skills, conceptual thinking, calculations, and orientation. The total possible score is 30 points; a score of 26 or above is considered normal but a cut-off score of < 21 appears to yielded good sensitivity and specificity (Lee, 2008).

2.3 Setting and materials

The experiments were conducted in two settings. The computer simulation experiment was conducted in a small, quiet room (such as in a typical laboratory setting) adjacent to but separated from the museum space which was where the Hecht museum experiment was conducted. The museum experimental environment was instrumented with sensor technologies designed to support objective and unobtrusive monitoring of museum visitors (Kuflik et al, 2012). These included a computer to run the experimental task and iPods at each station (museum exhibit). For the computer simulation environment, a computer with a 15 inch screen and a standard computer mouse was used for the delivery of participants' responses.

2.3.1 Spatial memory task: 'Travelling salesman problem'. The tasks were a modified version of the "Travelling salesman problem", so called because it refers to the need by travelling salesmen to remember which houses they have already visited including cases of no response or where they have made a sale. The task was transformed into a spatial search activity that assesses the ability to retain and manipulate information in spatial working memory. The participants were required to maintain and update an ongoing representation of previous searches in different locations and to develop an appropriate search strategy to be successful in the task (Owen, 1996).

All participants performed the task at both settings: via a computer simulation, (Simulation), and in the museum setting (On-site), in an order that was counterbalanced within each age group. The spatial working memory task required the participants to search a set of targets by "opening" (i.e., by clicking on the mouse button in the simulation setting or touching the iPod target with a finger in the museum setting). A click/touch caused the target to reveal whether it was empty or contained a token. During any given search, there was a single token hidden within only one of the targets. The participants had to successively open the targets until they located the token. Then another token was hidden. Once a token had been found within a target, that target could not be used to hide a token until the end of that round and the participant was not supposed to check it again. This requirement meant that the participants had to remember which targets had been opened so that they would not return to one that had already been visited. When all tokens were found, the round was over.

Two types of errors are possible in this task:

- a between-search error occurred when participants returns to a target in which they had previously found a token
- a within-search error occurred when a participant returns to a target within the same search.

Graphic display of the target content was similar in both settings. Empty targets were designated by an empty black frame shown above the target; errors were designated by a red "X" symbol shown above the target and the found token was designated by a green "*checkmark*" symbol. The salient instruction was that once a token had been found at a particular target (green "*checkmark*"), the target should not be checked again until the end of the round. The Frequency of success and Normalized time per target were computed for each round. Normalized mean time per target indicates the time it took to complete a given level divided by the number of clicks during this level (as the number of clicks made by participants during a given round was variable, depending on the individual search strategy).

Each participant performed three rounds of increasing difficulty in each setting; in the first round there were four target locations, in the second round five target locations and in the third round six target locations. In both settings, the target locations were pseudo-randomly arranged for each round to prevent transfer of previous knowledge to the next level. In the case of an error, the current round was aborted and the participant was given a second try to complete the current level. Before commencement of the actual experiment with four, five and six targets, three training rounds with three targets were performed in each setting, to familiarize the participant with the task.

Computer simulation setting: For the computer simulation setting, participants were presented with targets on a computer screen (see Figure 1). The search to successive targets was performed by navigating with a standard computer mouse and clicking the left button.

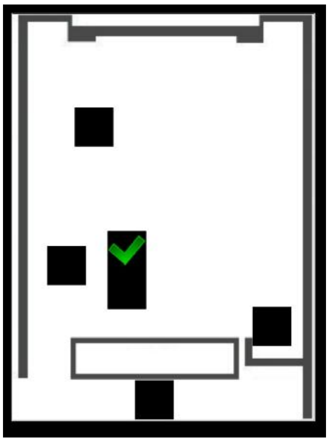

Figure 1. *Computer simulation setting screen example. Level 2: Five targets with one of the targets revealing a token (green "checkmark" symbol above the target), when participant clicked on this target.*

On-site museum setting: The on-site version of the task had the same structure and sequences of spatial arrangements of targets as the computer simulation. For the on-site task setting, participants were presented with targets on a touch-sensitive iPod screen, with each iPod placed on a stand at different specific locations in the museum space (see Figure 2, left and right panels). While the location of the iPods in the museum was real (stands with iPods were distributed among museum exhibits in a 40 by 40 meter hall), the tokens were virtual (i.e., they appeared on the iPod screen, if the target was opened by participant). iPod locations were spaced 2 to 30 meters from each other. On each iPod only one target (black square) was presented. Upon touching the surface, information regarding the target (i.e., existence of the token) was delivered in the same way as in the simulation setting. Participants were required to search through the iPods for a green "checkmark" token by touching each iPod to reveal its contents.

Figure 2. *On-site (museum) setting.* Left, *Experimental area in the museum,* Right, *Participant's hand selecting a target while searching for a token.*

2.4 Procedures

Ethical approval was obtained from the Institutional Review Board of the University of Haifa. Each participant was invited for a single, 60-75 minute session which started by signing informed consent, an explanation of the experiment and basic instructions. Participants were randomly assigned to first perform the simulation or the on-site task. The participants completed the questionnaires at the conclusion of the experiment.

3. RESULTS

The young adults group performed significantly better than the elderly group in both tested settings (simulation and on-site). This advantage was expressed in terms of both the frequency of success and the Normalized mean time per target (see Fig.1). Descriptive statistics for both measures are presented below.

Frequency of success. Differences between the age groups in frequency of success were found to depend for both setting, and level of difficulty (Table 1). When the round included only four targets, in the computer simulation setting, both young and older adults succeeded in finding all the tokens. In contrast, during the four-target round in the on-site setting, the older adults failed to complete the round significantly more frequently than the young adults. When the round included six targets, in the computer simulation setting, the older adults failed to complete the round significantly more frequently compared to young adults; for this level, there were no significant differences between the groups for the on-site setting. In the intermediate difficulty level (five-target round), there were no significant differences between the groups in the frequencies of success for either the computer simulation setting or the on-site setting. Nor were significant differences found in the frequencies of success within each age group between the computer simulation setting and the on-site setting.

"Normalized time per target". In a 3 ways repeated measures ANOVA, a significant main effect was found for group ($F_{(1,27)}$=35.86; p=.0001) and for setting ($F_{(1,27)}$=457.34; p=.0001). There was no interaction effect for the different difficulty levels with age group or setting in terms of the normalized time per target measure, meaning that increased cognitive load had no effect on the mean performance time. However, there was a significant interaction effect for age group and setting ($F_{(1,27)}$=7.28; p=.012); further analysis showed that differences between the age groups in the Normalized time per target measure were found in all levels within each setting with the older adults being slower than the young adults. (Figure 3, Table 2). In addition, in both groups significant differences were found between the two settings at all the difficulty levels.

Table 1. *Number (percent) of healthy young* (N =20) *and older adults* (N = 9) *who succeeded during the first trial in the simulation and on-site task*

	Simulation			On-site		
Level	Young Adults n (%)	Older Adults n (%)	χ^2	Young Adults n (%)	Older Adults n (%)	χ^2
4 targets	20 (100)	9 (100)	-	20 (100)	7 (77.8)	4.77*
5 targets	18 (90)	6 (66.7)	2.37	13 (65)	3 (33.3)	2.52
6 targets	17 (85)	2 (22.2)	10.83**	14 (70)	4 (44.4)	1.72

n – Number of participants who successfully completed a level; % - percent of participants who successfully completed a level; * p ≤ .05, ** p ≤ .00; - no statistics were computed as success rate was 100% in both groups

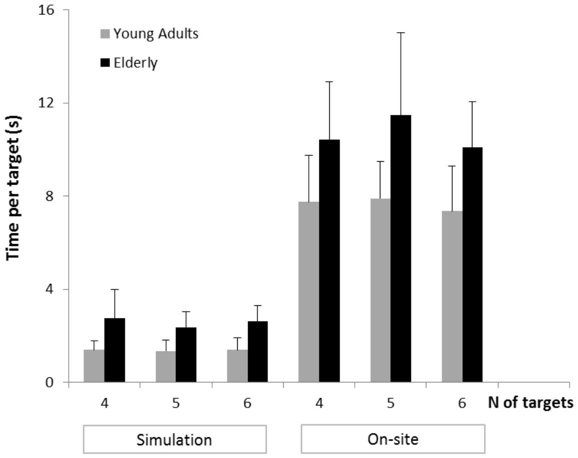

Figure 3. *Mean time (in seconds) per target, calculated as the mean time to complete a given level / by the number of clicks during this level. Black– elderly group (n = 9), Grey – young adults group (n = 20). Bars – SD. Results are shown for the three difficulty levels (N of targets) during the Simulation and On-site Museum performances.*

Table 2. *Means and standard deviations (SD) for the normalized performance time (seconds per click) of young and elderly subjects on a spatial memory task in a simulated environment compared to an on-site environment in different levels.*

	Simulation				On-site			
Level	Young Adults Mean ± SD	Older Adults Mean ± SD	F *df*(1,27)	η^2	Young Adults Mean ± SD	Older Adults Mean ± SD	F *df*(1,27)	η^2
4 targets	1.40±0.38	2.74±1.24	20.14*	0.43	7.76±1.99	10.44±2.48	9.62***	0.26
5 targets	1.35±0.48	2.35±0.68	20.66*	0.43	7.90±1.59	11.50±3.53	14.72**	0.35
6 targets	1.40±0.50	2.62±0.68	29.30*	0.52	7.36±1.93	10.10±1.97	12.32***	0.32

*p ≤ 0.000, ** p ≤ 0.001, *** p ≤ 0.01

4. CONCLUSIONS

The objective of this study was to test the ability to retain and manipulate information in spatial working memory in healthy young and older adults. Our results demonstrated the validity of the developed task that was applied in two experimental settings: the real museum space and the computer simulation. We showed that the paradigm implemented is a sensitive research tool that highlights cognitive and working memory differences in performance between the healthy young and older adult populations. Specifically, our results suggest that both age groups were sensitive to the increasing difficulty of the task, but responded in a different manner. At the easy level of the simulation setting, the older group did not show any deficit in the frequency of success to complete the round. As expected from the literature (e.g., Coubard et al, 2011; Deary, 2009), older adults were slower to complete all tasks than the young adults.

The study results suggest that healthy older adults maintain basic cognitive abilities required for successful performance in object–location memory task. However, the speed of performance as well as sensitivity to cognitive demands of the task are significantly altered by age with the older participants being generally slower in both settings and at all difficulty levels and less tolerant to increased extraneous cognitive load.

In rehabilitation, functional activity in real life situations is the most relevant outcome to measure (American Occupational Therapy Association, 2008). The current study implemented a test of spatial working memory in healthy participants from two age groups in experiments that tested the Living Lab approach to realistic and meaningful data collection (Følstad, 2008). Our results highlight the importance of experimentation in ecologically relevant settings: differences were found in the way the real setting affected the cognitive performance of older and younger adults. Such differences are expected to be even more apparent in clinical populations. A deeper understanding of age- and medical condition- induced constraints on working memory management may help in making an optimal use of the available cognitive processing capacity.

Acknowledgements: The authors wish to thank the Hecht museum at Haifa University for permitting us to use the museum space to run the experiments; Michael Sambur, Inna Belinki, Yaniv Nisenboym, Keren Tzitiad and Zohar Herling for their help in the software programming and data collection. Furthermore, the Caesarea Edmond Benjamin de Rothschild Foundation Institute for Interdisciplinary Applications of Computer Science (C.R.I.) is gratefully acknowledged for funding this project.

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Web accessibility by Morse Code modulated haptics for deaf-blind

L Norberg, T Westin, P Mozelius, M Wiklund

Department of Computer and Systems Sciences, Stockholm University,
Forum 100, Kista, Stockholm, SWEDEN

{lenan, thomasw, mozelius, matsw}@dsv.su.se

www.dsv.su.se

ABSTRACT

Providing information using a modality that is both non-visual and non-auditory such as haptic feedback, may be a viable approach regarding web accessibility for deaf-blind. Haptic navigation systems have been shown to be easy to learn (Venesvirta, 2008), and modulating navigation related information as patterns of vibrations has been shown to be perceived as natural and non-intrusive (Szymzcak, Magnusson and Rassmus-Gröhn, 2012). To minimise the bandwidth needed, a varying length encoding scheme such as Morse code may be considered. A prototype Morse code vibration modulated system for web page navigation was developed, using a standard game controller as a means of output. Results show that simulated deaf-blind test subjects using the system were able to navigate a web site successfully in three cases out of four, and that in some situations a version of the system with a higher degree of manual interaction performed better.

1. INTRODUCTION

Deaf-blind relies on routines and layout, where routines are the temporal ordering of events, while the layout is the spatial arrangement (Goode, 1990). The routines are signed in relation to context in the sense that the same sign can provide different meanings in different temporal and spatial contexts. The shared knowledge about both routines and layout enables an interpretation of the limited repertoire of expressions at hand for a person who is deaf-blind. Such signs are not equal to using a more generic sign language, which may also be used when communicating with a wider group than the family. (Ibid.) Thus, the interpretation is a key consideration in data collection as well as in design of human-computer interaction.

As discussed in (Thinus-Blanc and Gaunet, 1997) and (Klatzky, 1998), vision impaired persons are highly dependent on non-visual clues in their surroundings when navigating an environment. Much work has been done developing such clues, e.g. in the form of speaking signs and tactile rails on subway platforms. Without such clues, many places in the physical world pose a risk to the blind (Ceipidor et al, 2007). Also, regarding web content, work aimed at improving the accessibility for deaf and blind people, respectively, have been addressed (Debevc, Kosec and Holzinger, 2011; Di Blas, Paolini and Speroni, 2004). Providing non-visual and non-auditory clues, e.g. by haptic feedback in some form, may thus be a viable approach to enable web accessibility for deaf-blind.

The situation touches on possible independency challenges, as summarized by Fiedler (1991, p. 87): “Disabled people wanted access to, and enablement for, the same range of opportunities and responsibilities as their able bodied peers.”. While this issue is not limited to visually impaired, blind people lack allocentric frames of reference and as a consequence when navigating an environment are much dependent on tactile and audio clues in their surroundings (Klatzky, 1998; Thinus-Blanc and Gaunet, 1997). Other studies have suggested using audio in addition to the haptic experience (Gutschmidt, Schiewe, Zinke and Jürgensen, 2010; Sepchat, Monmarché, Slimane and Archambault, 2006), which may be useful for those deaf-blind users that have some auditive ability.

Furthermore, overview is important for a blind person (Karlsson and Magnusson, 1994). Typically, a screen reader presents a selection of text at a time, depending on the web page element currently in focus. It should be noted that a screen reader is independent of the output mode of the information, which may be presented with devices for speech synthesis or Braille. A screen reader may also present an overview of e.g. the number and type of elements on a web page. However, as many web pages are not properly designed according to W3C web accessibility standards, using screen readers can be problematic. For example, Lazar, Allen, Kleinman and Malarkey (2007) made a study of 100 blind users of screen readers using time diaries where they recorded their frustration while using the web. The problems were mainly caused by poor web design and were often time-consuming or even unsolvable for the user. (Ibid.)

According to Ford and Walhof (1999) Braille reading speeds of upward 200 to 400 words per minute can be achieved when learnt at a young age. In a study by Mousty and Bertelson (1985) mean reading speeds were 123.0 and 106.3 words/min for congenital and late blindness, respectively. As discussed by Thurlow (1986) Braille is the most established coding system, however with literacy rate not higher than 20% of the blind population (Lazar et al, 2007). Further, Braille has shown to be difficult both to learn and to discriminate tactually (Thurlow, 1986). While Braille is well established, the approach with Morse coded vibrations has some advantages. For mobile applications the relatively small form factor of vibrating actuators enables increased mobility. Further, the cost of a Braille display relative to a vibrating actuator is important to consider, especially in developing regions.

In a participatory design approach Zhu, Kuber, Tretter and O'Modhrain (2011) tested a haptic assistive web interface using HTML-mapping and a force-feedback mouse. Findings showed that participants were able to identify objects presented haptically, and develop a structural representation of layout from exploring content. Further, a comparison between three different haptic devices providing non-visual access to the web was made. Three areas of limitations were listed: ergonomic, device and psychophysical. In the first the users freedom of natural motion might be restricted; in the second, the design of the device gives different ways of experiencing a haptic force, which affect the performance and user satisfaction; the third show that certain haptic properties can be extracted more efficiently than others. (Ibid.)

To overcome limitations imposed by the lack of tactile feedback on touch screens, V-Braille, represent Braille characters with haptic vibration (Jayant, Acuario, Johnson, Hollier and Ladner, 2010). With V-Braille, the screen is divided into six squares each corresponding to one of the six dots, which together represent a singular Braille character. Results of a reading test showed that it took between 4.2 and 26.6 seconds to read a V-Braille character for nine deaf-blind test users. The nine test users also reported they were very enthusiastic about V-Braille. (Ibid.)

People suffering from Ushers syndrome, constituting about 50% of the deaf-blind in the US, are more likely to become deaf-blind as adults due to aging rather than being affected from birth (Jayant et. al 2010). According to Venesvirta (2008) "Haptic navigation devices can be learnt to use fast, even after short practise." This could be especially beneficial for people who become deaf-blind at an older age when learning obstacles may be higher, such as a hearing impaired person who develops macular degeneration later in life. From a training perspective, we therefore suggest the use of a haptic modality to support deaf-blind people when navigating the Web.

Navigation using vibrations has also been used by Szymzcak, Magnusson and Rassmus-Gröhn (2012) in the Lund Time-Machine, a system that uses sound and vibration feedback to help users navigate through the medieval part of a city. While perceiving sounds from the middle ages, bearings and distances to points of interest was communicated through vibrations. The system was implemented as an Android app and used on a mobile phone. Findings include that patterns of vibrations used to communicate direction and distance are perceived as natural and non-intrusive by the users. (Ibid.) From a usability perspective, we therefore suggest that vibration may be an appropriate modality to support deaf-blind users who navigate the Web.

An interesting aspect of the findings in (Pascale, Mulatto and Prattichizzo, 2008) is that while using variations in the vibrations themselves has potential to convey more information, the test subjects still reported some remaining difficulties, indicating the need for a more elaborated encoding/modulation scheme. Thus, this study examines Morse encoded vibrations as a possible venue. As Morse code is a varying length encoding system (Golin and Rote, 1998) it may, given a character distribution in accordance with Morse code's intended frequency distribution, be used to represent information with a minimum of vibration bandwidth.

There are a number of technical prerequisites to implement Morse encoded vibrations. First, the application needs access to the information to be presented, which in this pilot study consists of text accessible through a web browser. Second, the application must be able to communicate with hardware, preferably via USB which at current is the de facto standard hardware interface for human interface devices, in this case an Xbox360 controller. Since there is only output to the device there is no need of handling polling or interrupts of the hardware (Gregory, 2009). Third, the application should be open and platform independent, to ensure both longevity and scalability of the solutions, as far as possible.

2. RESEARCH PROBLEM AND QUESTIONS

While haptics has been found to be a viable communication approach for deaf-blind, Morse encoded haptics adds the advantage of representing information with a minimum of vibration bandwidth. This approach may allow the use of low-cost devices with some haptic capabilities such as handheld game controllers. As these have not been implemented with the purpose of web browsing by deaf-blind users, the outcome of such use is unclear. In this pilot study the questions are: 1) Is a game-type controller suitable for implementing a vibrating web interface intended for the deaf-blind?; 2) Are simulated deaf-blind users (blindfolded and with ear protection) able to discern Morse-coded information modulated through vibrations, enabling them to understand the content of menu links?; 3) How will system designs with different degrees of interaction affect the outcome? The significance of finding answers to these questions is related to possible redesign of the solution presented here, followed by the inclusion of real deaf-blind users in tests.

3. METHODOLOGY

3.1 Design Science

The overall framework for this study is design science, a special strand in design research that has its roots in the areas of information systems and IT. Design science aim to create new and innovative artefacts to support people in using, maintaining and developing IT devices and systems. The artefacts in this sense are human made solutions to practical problems, and can be physical devices as well as blueprints, methods, or sets of guidelines. (Johannesson and Perjons, 2012). These artefacts are not isolated phenomena since they are embedded in larger contexts and have relationships to people and people's problems.

A design science process can be divided into five main steps where the first two, involving explicating the problem by investigating and analysing the practical difficulty or need at hand, and defining requirements for a solution, have been touched upon so far. The remaining steps of the design science process involve one or more iterations of developing, demonstrating and evaluating the various implementations of the artefact, out of which the first two versions will be discussed in the remainder of this paper.

During the iterations of the evaluation phase, the design science framework typically use traditional research strategies such as experiments or case studies to compare the different versions of the artefact and its relation to the intended users. Hence, the study complies with (Johannesson and Perjons, 2012) in that the two iterations performed so far were treated as an experiment, comparing the first two implementations of the artefact using two groups of test subjects.

3.2 Limitations

In this study we constrained the area of interest to information accessible through a web browser, and also not to make a solution for devices such as screen readers. The reason was to focus on communication principles and to be able to evaluate the outcome with pilot test subjects, before focusing on the optimal technical solution for a final implementation. None of the test subjects had any previous experience using Morse code, thus the only such training the test subjects received was during the 20 minute familiarisation period immediately prior to the test session. At this stage of the testing the main objective was to evaluate the possibility of detecting different combinations of long and short vibrations, which is a prerequisite to interpret Morse code.

3.3 Study Setup

A pilot study using four test subjects simulating deaf-blindness using blindfolds and ear protection was carried out. The study included development of a prototype software system to explore how the translation of the information could be done, and to evaluate how simulated deaf-blind users perceived the vibrating Morse signals. Since deaf-blind individuals are scarce, it is important to preserve this resource to test situations where technical errors and flaws in test design have been addressed, motivating the initial use of non-deaf-blind test subjects. One example of a pilot study successfully using two fully sighted and hearing test subjects wearing blindfolds and ear protection to simulate deaf-blindness can be found in (Owen, 2008). Issues of using simulated test-subjects versus actual deaf-blind are discussed in (Ranjbar, 2008), noting that deaf-blind subjects are more used to interpret vibrations. However, from a practical perspective the simulated setup can be motivated (ibid).

Demographic data of the test subjects in our study were as follows:

- Test subject 1: 38-year-old male, trained professional 3D-graphics designer
- Test subject 2: 40-year-old male, trained professional web site developer
- Test subject 3: 44-year-old male, senior university lecturer in Computer Science
- Test subject 4: 46-year-old female, project manager with a B.A. in Pedagogy

The prototype, called the GamePadServer, was implemented as a local web server on the user's PC, which modulates the vibrations of an Xbox360 controller. The GamePadServer handles two events, triggered by the user in a web client; the connect event is triggered by a button on a web page when the user wants to use the device; the message event is triggered by another button and sends the text to be translated into Morse encoded vibrations to the GamePadServer. A widely available, consumer oriented Xbox360 hand-held game controller was used as a means of output.

Data collection was performed using a subset of the cognitive walkthrough method, where the test subject conducts a task with a predefined goal typical of an end-user scenario, while playing the role of a person in the defined target group. Further, the task is conducted in a predefined system. (Wharton, Rieman, Lewis and Polson, 1994) As the predefined system, the Stockholm University computer- and systems sciences department website was used. The Swedish language version was used, with link names later translated to English for the purpose of appearing in this paper.

Four test sessions were conducted, with each test subject present individually. The test subjects wore blindfolds and ear protection, simulating deaf-blindness. During all four tests, the GamePadServer system allowed the user to detect the edges of the web page through vibrations in the hand-held controller. When the cursor was moved near the browser borders it caused the controller to vibrate accordingly.

The first group of two test subjects used version 1 of the GamePadServer system, requiring the user to click on a link (not causing the link to be followed) to initiate the Morse code vibrations representing the link to start. The links can be detected by the transmission of a link prefix when the cursor hovers over the link. The version 1 system then waits for the user to click again if (s)he wants to follow the link.

The second group of two test subjects used version 2 of the GamePadServer system, not requiring the user to click on anything for the Morse code vibrations to start. This follows after an initial transmission of a link prefix identifying the link type. In the version 2 system, a link prefix consisting of a fast train of five vibrations is sent when the cursor hovers over a image link, while a link prefix consisting of a single long low-frequency vibration is sent when the cursor hovers over a text link. If the user then takes no further action for a short interval, the Morse code vibrations representing the link will start automatically.

Figure 1. *Test setup showing use of laptop touch pad for input and Xbox360 controller for output. Test subjects were blindfolded and wore ear protection.*

Each test subject was given 15 minutes time to familiarise themselves with the system before the test began. This limited time represents the only training in interpreting Morse code that the test subjects received, as none of them had any such training before participating in the test.

Both groups of test subjects were asked to perform the same set of five tasks (T):

- Find a link on the page and indicate when one link was found (T1)
- Move the mouse pointer and indicate when it approaches the edge of the browser window (T2)
- Find the link "Research" (T3)
- Find the link "Employee" and follow it to get to that webpage (T4)
- Find the link "Library" on the "Employees" page (T5)

For tasks 1 and 2, two questions were answered, based on the performance of the test subject. Since tasks 3-5 involve locating a specific entity, a third question is also answered.

The questions (Q) answered in conjunction with the tasks were:

- Will the user find the control that is addressed in the task? (Q1)
- Will the user recognise that the control is of the right type? (Q2)
- Will the user recognise that the control is the specific control sought for? (Q3, only relevant for T3-T5, and in the case of T4 also implying success in using the control)

After the test each test subject had an opportunity to express possible additional information regarding the test subject's perception of the experience.

4. RESULTS

4.1 Hardware

The Xbox360 controller was found to be of limited use. The vibration motors have slow acceleration and deceleration rates, making the signalling unnecessary time consuming. Still, even with the limitations of the controller, the user test showed that it was possible to discern types of vibrations, e.g. links and edges of pages, and even though the test subjects were inexperienced with Morse code, three out of four were also able to distinguish between several links.

4.2 Test Sessions

Results from the four test sessions are shown in table 1. Questions ultimately answered positively but only after several tries or other initial difficulty are noted as "With effort". Please note that questions and answers in this context does not refer to regular question/answer sessions, but were rather answered by the test leader by observing the performance of the test subjects, also taking into account some verbal indications being made in the process. Test subject 4 aborted task 5 after failing to achieve a positive result regarding question 1, and thus choose not to attempt the activities associated with question 2 and 3 for that task.

Table 1. *Results from testing the GamePadServer version 1 and 2 with two test subjects (Ts) each. Five predefined tasks were attempted while simulating deaf-blindness, evaluated through two to three questions each, as detailed in the methodology section.*

		GamePadServer ver. 1		**GamePadServer ver. 2**	
		Ts 1	**Ts 2**	**Ts 3**	**Ts 4**
Task 1	**Q1**	Yes	Yes	Yes	Yes
	Q2	Yes	Yes	Yes	Yes
Task 2	**Q1**	Yes	Yes	Yes	Yes
	Q2	Yes	Yes	Yes	Yes
Task 3	**Q1**	Yes	Yes	Yes	Yes
	Q2	With effort	With effort	With effort	With effort
	Q3	Yes	Yes	No	No
Task 4	**Q1**	With effort	With effort	With effort	No
	Q2	Yes	With effort	Yes	No
	Q3	Yes	Yes	Yes	No
Task 5	**Q1**	Yes	Yes	Yes	No
	Q2	No	No	With effort	Aborted
	Q3	No	No	Yes	Aborted

4.3 Quotes from Test Subjects

In addition to the results listed in table 1, the test subjects expressed the following additional information regarding their perception of using the system (translated by the authors for the purpose of appearing in this paper):

"I gradually made a mental image of the web page, and to some extent I began to count the number of links I passed to know where I were on the page. It took a long time waiting for a link to finish vibrating, before it was all through. For someone skilled in Morse Code, the system could probably use a higher speed. The controller is a bit clumsy, the vibrations are not so easy to distinguish from one another." (Ts 1)

"It was interesting. But hard. I got tired towards the end. I tried to remember where the links were. The hand controller vibrate very much. It wasn't pleasant, and quite big." (Ts 2)

"Sometimes there was a delay when I moved the cursor to a new place, it took a little time before the vibrations changed. You should make it possible to jump between links with the arrow keys. Morse vibrations seems very fast, maybe you should slow it down a bit. Maybe you could put in a function to pause, but it should only pause between two words." (Ts 3)

"It was easy to feel the difference between an image link and a text link, but seems extremely hard to understand what the link says. It was hard to see in my mind where the cursor was on the page. It was hard to find the Research and Employees links. At the end I just felt a blur of vibrations, a got really tired." (Ts 4)

5. DISCUSSION

5.1 Tested tasks

As shown in table 1, task 1 and 2 were carried out successfully by all four test subjects, indicating that both version 1 and 2 of the GamePadServer were capable of communicating basic navigation information such as the presence of a link or a page border to the user. Regarding task 3, involving locating a particular link, some differences are shown. While all test subjects found the link (Q1), it took additional effort in the form of one or more retries before they were convinced that it was the correct one (Q2).

In the case of task 3, neither of the test subjects in the GamePadServer version 2 group (Ts 3 and Ts 4) achieved a positive result regarding Q3, and thus were not able to identify the link as the particular one sought for. This was not a problem for test subjects 1 and 2 in the GamePadServer version 1 group. One possible explanation for this is that the manual behaviour of the version 1 system, requiring a click on the link before starting to transmit the Morse code representing the link, provided an opportunity for the test subjects to gather their thoughts before continuing. This may be a desirable arrangement for non-experienced users, while it is still possible that the automatic behaviour of GamePadServer 2, automatically continuing with the transmission of the link after a short pause without waiting for any action from the user, may be desirable for more experienced users.

Tasks 4 and 5, implying both locating and following a particular link, and in the case of task 5 then locating another link on the new page, showed more varying results. In task 4, both test subjects in the GamePadServer 1 group succeeded in following the link in question (Q3) after varying degree of effort, while one of the test subjects in the GamePadServer 2 group succeeded (with no effort) and the other was unsuccessful altogether.

In contrast, in the number 5 task, none of the test subjects in the the GamePadServer 1 group succeeded (other than initially locating a link (Q1), however not the right one. Here, test subject 3 (using GamePadServer 2) reached the ultimate goal (Q3) for task 5, after some effort identifying the link to be followed. Test subject 4 gave verbal accounts of being tired and choose to abort the remainder of task 5 after failing initial identification of a link (Q1), but since none of the GamePadServer 1 users succeeded with this task it was only accomplished successfully using GamPadServer 2, by one of its test subjects. While this pilot study does provide the insight of a working concept, a larger study is needed to evaluate the implementation details further.

5.2 Verbal feedback

Opinions on speed of the Morse code transmissions varied, from *"For someone skilled in Morse Code, the system could probably use a higher speed"* (Ts 1) to *"Morse vibrations seems very fast, maybe you should slow it down a bit"* (Ts 3). Two of the test subjects mentioned undesirable properties of the Xbox360 controller when used in this context, describing it as *"clumsy"* (Ts 1) and *"quite big"* (Ts 2). This indicates that smaller controllers, possibly including those designed to be attached to the body rather than hand-held, may be used instead.

It is worth noting that three of the four test subjects spontaneously expressed various notions of picturing the web page, or remembering the positions of links on the web page, in their minds. However, adopting such an approach, and trying to relate that information to what was happening on the web page, may not be typical for actual deaf-blind persons. It seems possible that the test subjects, being sighted and only temporarily simulating (deaf-)blindness, retain a visually oriented mindset not necessarily present among (deaf-)blind users attempting to use the GamePadServer system.

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6. CONCLUSIONS

A game-type controller can be successfully used as an output device for a vibrating web interface intended for the deaf-blind. Based on feedback from test subjects, its size and shape are perceived less ideal by some, indicating that more suitable devices likely can be found.

Simulated deaf-blind users (blindfolded and with ear protection) were able to identify vibrations indicating presence of links and page borders, and in three cases out of four were able to discern Morse-coded information modulated through vibrations, enabling them to understand the content of menu links.

A manual system design requiring test subjects to click on links to start Morse code transmissions was successfully used in two cases where a design with a more automatic interaction principle was unsuccessful, while the automatic system was successfully used (with effort) in one case where the manual system was unsuccessful.

7. FUTURE RESEARCH

Initial positive results from the work described here merits a study involving a larger number of test subjects, as well as a longer usage period of the developed technology. A shift from technical proof-of-concept to a focus on users' perception of the tested accessibility mechanisms is a natural next step.

Focusing on perceived usefulness may lead to a deeper understanding regarding preferred functionality by the intended target group. Further refinement should ideally be conducted as a teamwork involving users and researchers in the form of a constant feedback loop, utilising the users' attitudes as a frame of reference when selecting future features of the system.

The strategy of remembering displayed by the test subjects in some cases may be related to the need for routine and layout (Goode, 1990). This is dependent on the website structure to be static, which neither the end-user nor the developer of accessibility solutions have any control over. Thus, a question for further research is to find a method to explore if existing web server technology intended to detect whether a previously visited website structure has changed, can be feasibly made use of, thereby guiding the user in the choice between strategies of exploring or guessing.

Acknowledgements: This work was made possible by funds from The Swedish Post and Telecom Authority.

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Intensive language-action therapy in virtual reality for a rehabilitation gaming system

K Grechuta[1], B Rubio[1], A Duff[1], E Duarte Oller[2], P Verschure[1,3]

[1]Pompeu Fabra University Laboratory of Synthetic Perceptive, Emotive and Cognitive Systems, Center of Autonomous Systems and Neurorobotics (SPECS), C/Boronat, Barcelona, SPAIN

[2]Servicio de Medicina Física y Rehabilitación. Hospital del Mar i l'Esperanza, IMAS Barcelona, SPAIN

[3]ICREA - Institució Catalana de Recerca i Estudis Avançats, Passeig Lluís Companys Barcelona, SPAIN

{klaudia.grechuta, belen.rubio, armin.duff}@upf.edu

ABSTRACT

One third of stroke patients suffer from language disorders. These disorders severely impair individuals' communication abilities, which impacts on their quality of life. Recently, the Intensive Language Action Therapy (ILAT) emerged as a novel paradigm for aphasia rehabilitation. ILAT is grounded in three main principles: intense practice, overcoming the learned non-use, and an individualized training. In the present study we designed and developed a VR based language rehabilitation tool by integrating ILAT's object request LAG in RGS, a novel paradigm for the rehabilitation of motor deficits after lesions to the central nervous system. RGS is a gaming environment that provides a multimodal, task specific training in virtual reality scenarios. Its special design consists of an intelligent motion detection system that monitors the users' movements. This allows for an active interaction as well as continuous evaluation of the affected limbs. We addressed the question whether aphasia rehabilitation designed within the VR environment of RGS can be an effective tool. The principal purpose of the initial pilot study was to validate the system and to learn whether a virtual adaptation of the ILAT into RGS can trigger positive changes in the linguistic behavior of Broca's aphasia patients. We report the results of a double-case initial pilot study where one acute and one chronic aphasic patient followed five RGS-ILAT therapy sessions. Before and after the treatment we evaluated their language skills using the Communication Activity Log (CAL) and Western Aphasia Battery (WAB) scales. Results show that the patients learnt how to interact within the VR system. The CAL performance suggests that both patients and their therapist perceived improvements in the communication skills after the therapy. Additionally, the approval and acceptance of the system were high. Based on this initial outcome we will further provide the present RGS-ILAT with substantive technological advancements and evaluate the system to reliably replicate the original ILAT, in order to better understand the potential of the virtual reality based language rehabilitation therapies.

1. INTRODUCTION

Stroke is a neurological disease which causes the most common disabling neurological damages (Carter et al, 2012). 35-40% of stroke patients suffer serious language deficits, such as aphasias, which are often accompanied by anxiety, depression or social withdrawal (Elman et al, 2000). Traditional aphasia therapies focus mostly on repeating words, where the complexity of the practiced language gradually changes from less to more frequent. These methods usually do not put emphasis on the importance of an intense practice of language adapted to the personal needs of each patient, within a meaningful context. Alternative treatment and rehabilitation methods are therefore required in order to achieve successful recovery.

Recently, the relation between language, cognition and its neural substrate has shed light onto the composite structure of the language processing and production systems as well as the effective rehabilitation of language deficits caused by stroke (Ozyürek et al, 2007; Pulvermuller, 2005; Gubailovskii et al, 2008). The brain comprises a set of interconnected neural circuits where linguistic, or any other, motor, perceptual or attentional abilities cannot be separated into discrete modules (Carter et al, 2012). Therefore, for a therapy to be effective, in the brain there must be an interaction between linguistic neural system, motor and sensory circuits, memory, planning and monitoring (Kurland et al, 2012). It has been shown that both words and complex sentences, which are semantically related to actions that involve different parts of the body, activate the sensorimotor cortex (Pulvermuller, 2005; Berthier and Pulvermüller, 2011). This observation has led to the hypothesis that sensorimotor circuits provide the cortical basis for language (Pulvermuller, 2005). Accordingly, language processing, both comprehension and production, is physically linked to the action systems. This is consistent with the general view on the tight coupling of sensing and action in the brain (Verschure et al, 2003). Being embedded within the sensorimotor system, language processing is coupled to one's bodily experience, which suggests a novel route for the rehabilitation of language deficits. Indeed, it has been reported that a specific action oriented language training can result in considerable improvements in both language performance and its underlying cerebral activity related to language, in both Wernicke's and Broca's aphasia patients (Pulvermuller, 2005). The research on the reorganization of language related brain areas, which follows rehabilitation, suggests that neural plasticity and reorganization can even result in shifts in language lateralization (Neville et al, 1998). These findings have changed the approach towards the language rehabilitation reinforcing the stimulation of multiple brain regions creating conditions for recovery (Carter et al, 2012). The range and types of language rehabilitation techniques have been further amplified by using a range of technologies including virtual reality tools, which have shown to be successful in treating deficits resulting from stroke (Abad et al, 2013; Cameirão et al, 2007; Cameirão et al, 2010; Cameirão, 2012). In particular, we have shown previously that an approach, which combines mirroring through VR with specific brain-theory based training protocols, or the Rehabilitation Gaming System (RGS), can be highly effective in the rehabilitation of the upper extremities in acute and chronic stroke patients (Cameirão et al, 2007; Cameirão et al, 2010; Cameirão, 2012). Here, we further extend this RGS approach by augmenting it with a VR based version of ILAT. In particular we investigate the question whether RGS-ILAT is effective in treating stroke induced Broca's aphasics (Difrancesco et al, 2012).

1.1 ILAT and Broca's Aphasia

ILAT is a Speech and Language Therapy (SLT) approach that aims at reinforcing the activation of both linguistic and its underlying motor circuits in a systematic and structured way by means of intensive practice and contextualized game scenarios (Pulvermuller, 2005). The therapy focuses on treating Broca's aphasia that results from the lesion to the left frontal cortex (Boo et al, 2011). The syndrome is characterized by disorders in the syntax of language production including motor disorders and agrammatism. Individuals who suffer this type of aphasia are typically not fluent when speaking and often cannot combine words into meaningful sentences (Marshall, 2008). Patients who suffer from Broca's aphasia therefore may benefit from rehabilitation methods that focus on the reinforcement of full sentence production as well as general fluency. Within this context, Pulvermüller et al. emphasize three main premises of ILAT (Difrancesco et al, 2012). The first one is the intensive training (e.g. 3h/week for 2 weeks). Secondly, ILAT exploits the behavioral relevance of the therapeutic context, namely, the embodiment of speech within a communicative, natural, action context. Finally, the authors suggest the use of behavioral techniques such as shaping, modeling and positive reinforcement. Indeed, recent studies show that even patients with severe Broca's aphasia and/or Apraxia of Speech (AOS) can improve when undergoing ILAT (Kurland et al, 2012). In the present study we propose a new rehabilitation scenario that combines ILAT and RGS. We believe that the original ILAT may benefit from its VR implementation, which allows for the implementation of multimodal feedback, and provides wider accessibility.

1.2 ILAT Scenario

There are 3-4 players who take part in the original ILAT session. One of the players is a Speech and Language Therapist (SLT), whose role is to actively monitor the patients, keep track of utterances, model speech and adjust the velocity of the game. The rest of the participants are patients with post-stroke Broca's aphasia. The Original ILAT consists of two types of Language Action Games (LAGs): the object request LAG (see Fig. 1) and the action-planning LAG (Difrancesco et al, 2012). The object request LAG begins when all the participants are given identical sets of cards (from 6 to 12 each). The player who starts the game (player A) selects one card and holds it in his/her hand, so that the other participants cannot see its content. Next, s/he verbally requests the same card from another player (player B). The possible moves that can follow depend on whether the player B owns the requested card. Player B can therefore either follow the request and pass the corresponding card, or reject the request. Further clarification attempts can occur in case of misunderstandings between the players. The goal of the object request LAG is for the player to be the first with no cards left on the table. This can be achieved by either passing or receiving the matching card/s. In the present project we have implemented the object request LAG protocol in RGS by rigorously following its language-action structure.

1.3 RGS

RGS is a novel paradigm for the rehabilitation of motor deficits after lesions to the central nervous system (Cameirão et al, 2010). It is a gaming environment that provides a multimodal, task specific training in virtual reality scenarios (see Fig. 2). Its special design consists of an intelligent motion detection system that monitors the users' movements. This allows for an active interaction as well as continuous evaluation of the affected limbs. The original purpose of the system is to provide a novel rehabilitation tool to treat motor deficits of upper limbs in post stroke patients. RGS deploys a number of scenarios which can be adjusted to the specific needs of the users. That allows for a continuous interaction with the Virtual Environment (VE). The computer-generated world is viewed form the first person's perspective, and all the events that happen within the VR are under real-time user control. RGS has proved to be successful in the number of clinical trials (Cameirão et al, 2007; Cameirão et al, 2010; Cameirão, 2012). We see RGS as an example of the novel field of science-based medicine where interventions are based on causal theories of brain and behavior. Its tracking system, individualized training and reinforced visual feedback (Cameirão et al, 2010) allow for the integration of ILAT.

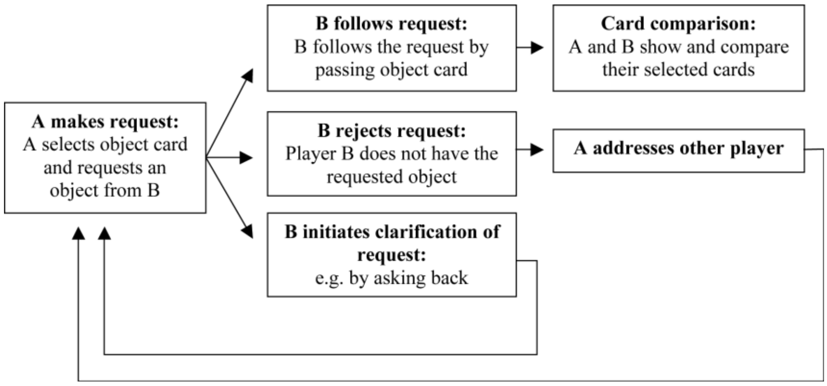

Figure 1 *Object Request LAG. The diagram presents possible decisions that can be make during the game (Difrancesco et al, 2012).*

The aim of the present study is therefore to extend the range of the rehabilitation focus that RGS originally provides to the rehabilitation of Broca's aphasics and to learn about the potential benefits of VR based language rehabilitation techniques.

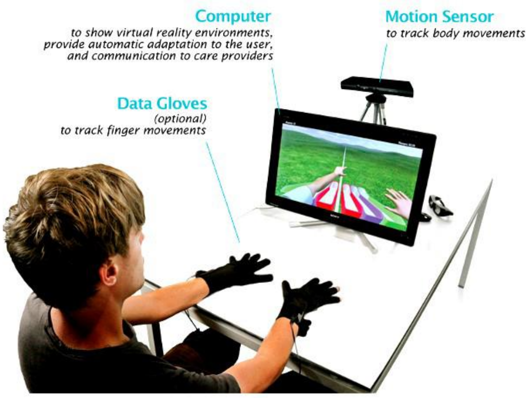

Figure 2 *Rehabilitation Gaming System (RGS) setup. The subject works with his/her arms on a cut-out table facing a computer screen. The movements of the arms are tracked by the Kinect. The captured movements are mapped in real time to the movements of two virtual arms that mimic the movements of the user on the display.*

2. METHODS

In the present study we built a VR version of ILAT using the Rehabilitation Gaming System (RGS) in order to investigate the potential of VR based language rehabilitation methods. We conducted a double-case initial pilot study in order to test the system. Additionally, we evaluated the patients' language skills before and after the intervention.

2.1 System Description

The software of the present system is integrated within the environment of the RGS. The experimental setup consists of two standard personal computers (Vaio L Series All-in-One PC, Tokyo, Japan) with a 24" (61cm) Full HD touch screen, two motion sensing input devices (Xbox Kinect, Seattle, USA) and a networking system.

2.2 Virtual Scenario

The virtual environment was designed and developed using Unity3D game engine (Unity Technologies, San Francisco, USA). The motion tracking system (Xbox Kinect, Seattle, USA) captures and maps the movements of the users' real arms onto those of the avatars. Consequently, during every session all users can continuously observe the movements of both their virtual arms' and those of the opponent/s.

The training scenario takes place in a shared virtual room, to which the players connect via a local network. Each of the users can see three objects placed on the virtual table (see Fig. 3). In the beginning of the game one of the players is indicated to start the game. Consistent with the original request LAG scenario, his/her task is to first choose one object from those available on the table and then verbally request the same object from the opponent. In case of a successful communication the opponent should understand the request and pass the corresponding object. Such a sequence of events accounts for a successful communicative interaction, for which both players get a point.

The interaction with the virtual objects is based on delays. Thus in order to select or to pass an object, depending on the turn, players needs to place one hand over that object for 2-3 seconds. If the passed object matches the requested object they both appear in the basket which belongs to the player who started the round. At the same time the patients' scores increase, two new objects appear on the table, and the turn changes. After such sequence of events, the second player is required to choose and request an object. The selection of objects is indicated by a short animation and a corresponding sound (e.g. a piano melody, in case of the piano; heartbeat in case of the heart; or footsteps in case of a shoe). We decided to incorporate sounds in order to provide additional associative cues assisting in recall and to help the patients in retrieving the words. All the objects light up whenever they are being pointed to. The purpose of the visual feedback is to enhance the salience of relevant objects and to ease the interaction with the system. Additionally, during the period of object selection an animated wall appears in the middle of the table. This prevents the opponent from seeing not only what object is being selected, but also possible indicative gestures. As soon as an object is selected, the wall disappears and the players can see the opponent's virtual avatar. Instructive headings such as "It's Your Turn", "Well Done", "Try Again", or "Game Over" are displayed every time an event in the game changes (change of turn, collection of an object, failure, end of the game etc.). Since the system was tested in the Hospital Esperanza in Barcelona, Spain, the User Interface (UI) is written in Spanish.

Figure 3 *The virtual scenario of Intensive Language Action Therapy in Virtual Reality from the first person perspective. The virtual objects are placed on the virtual table as well as in the baskets on the sides. The opponent is sitting at the other side of the table.*

2.3 Setup

All the phases of the study took place in the Hospital de la Esperanza, in Barcelona, Spain. In a speech therapy ward, two computers were placed in front of each other so that the players could be close enough to efficiently communicate with one another. The seats were placed so that the patients could not see the opponent's real hands while selecting the virtual objects.

2.4 Protocol

Each of the patients participated in three phases of the study: a system evaluation phase, a training phase and an intervention phase. Both patients completed excerpts from Western Aphasia Battery (WAB) before and after the intervention, to be later analyzed. WAB is a standardized measure commonly used to assess the function of language which includes: Spontaneous speech, Auditory verbal comprehension and recognition, Sequential commands, Repetitions, Object naming, Word fluency Sentence completion Responsive speech andReading comprehension of sentences and commands. After completing the evaluation, patients participated in twenty-minutes training phase. During this phase a healthy player and a speech therapist were performing the virtual task. Meanwhile, the crucial parts of the game were being explained: system's startup, gaming rules and objectives. The next day the training phase took place (20 minutes). Two patients were asked to play against each other, and later they were interviewed about the usability of the system. Based on the foregoing evaluation slight changes were immediately incorporated with regards to the objects displacement within the VE. As the pre-phase period was completed the patients started the intervention which lasted for five days. Each of the patients played against the healthy player in the presence of a speech therapist. The role of both the healthy player and the therapist was to actively monitor the patients, keep track of their utterances, and adjust the velocity of the game, while the record of patients' successes and failures was stored by the system (RGS). Date, the session number, time, utterance type, quantity of failures, as well as scores from every session were continuously registered for further analysis. Moreover, all the sessions were recorded to extract Reaction Times (RTs) and to later analyze the data gathered from every session as suggested by the original study (Difrancesco et al, 2012). RTs were measured from the moment when the patient selected the object to be requested from his/her opponent to when s/he fully uttered the correct name of the corresponding object. The game events, which included failures, names of the indicated objects, points, and the acts of selecting and passing the objects were continuously logged and stored after every session.

In order to further measure the potential change on a communication rating scale, the two patients as well as the speech therapist completed the Communicative Activity Log (CAL) before and after the intervention (Pulvermuller, 2005). CAL is a qualitative tool to measure patients' amount and quality of communication in everyday life. CALs' questions regarded the frequency with which patients would communicate in everyday life situations such as shopping, talking on the phone, answering/asking questions, and more. The questionnaire consisted of 18 questions to be answered on a 6-point Likert scale. The scale ranged from 'never' to 'very frequently'. Additionally, after the period of the intervention, both patients were asked to complete a 16-item System Validation Questionnaire (SVQ) presented on a 7-point Likert scale.

2.5 Subjects

Two post- left hemispheric stroke patients (See Table. 1), C.G.G. (man, aged 75, right- handed) and T.H. (woman, aged 52, left- handed) participated in the three experimental phases. Both subjects had normal vision and suffered from post stroke Broca's aphasia. For the purpose of the present pilot study the exclusion criteria only partially followed the protocol introduced by Pulvermüller (Difrancesco et al, 2012). We therefore first made sure that the two subjects did not suffer chronic heart disease or any related illnesses which makes the participation difficult. Secondly, the subjects could not suffer from any disease which would prevent from understanding the instructions of both the scenario of the LAGs and the interaction with the system itself. Therefore, the presence of impairments which affect perception as well as motor and neuropsychological functions such as deficits in motor planning (apraxia), vision, learning, memory or attention were accordingly evaluated and excluded.

Table 1. *Clinical data about the patients who participated in the study (C.G.G. and T.H.)*

Patient	Native language	Months after onset	Origin of the stroke	Lesion Site	Type of aphasia	Severity of aphasia
C.G.G.	Spanish	15	Hemorrh-agic	Left frontote-mporal	Non-fluent	Very severe
T.H.	Bengali/ English	1	Atheroth-rombotic ischemic	Left middle cerebral artery	Non-fluent	Moderate

3. RESULTS

The present study was designed to investigate whether VR based language rehabilitation systems can trigger positive changes in the communicative behavior of post stroke Broca's aphasia patients. We approach our aim by designing and testing ILAT in RGS system. Together the results presented here reinforce the notion that such novel techniques should be further investigated to better understand their efficiency and usability.

3.1 Clinical evaluations: CAL and WAB

Results from CAL show improvements in all the evaluations in both patients (see Fig. 4). From the overall score of 90 points, the speech therapist assigned 43 points before and 47 points after the intervention to C.G.G. which means that the score increased by 9.3%. An increase was also reported in case of T.H. The score given by the therapist to T.H. prior to the intervention equaled to 19 points, and increased to 32 points after the treatment. The score increased by 68.4% after the intervention. Improved results from CAL were also observed in patients' self-ratings after the intervention. The score of C.G.G. increased by 14.7%, and the score of increased by T.H. by 27.9%.

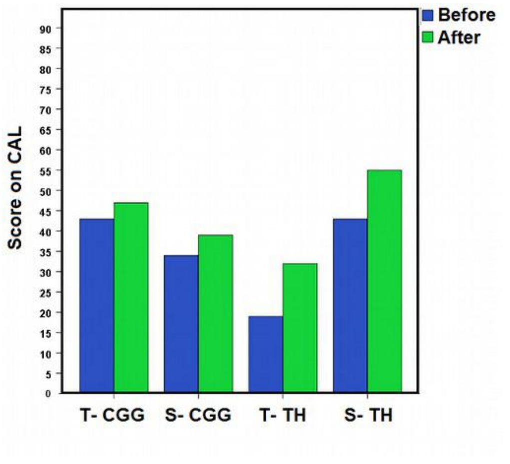

Figure 4. *Pre- and post- results from CAL for CGG and TH. Blue bar: results from the pre-evaluation, green bar: post-evaluation. T-CGG: therapist's evaluation of CGG T-T.H.: therapist's evaluation of T.H., S-CGG: self-evaluation of CGG, T-TH: self-evaluation of TH.*

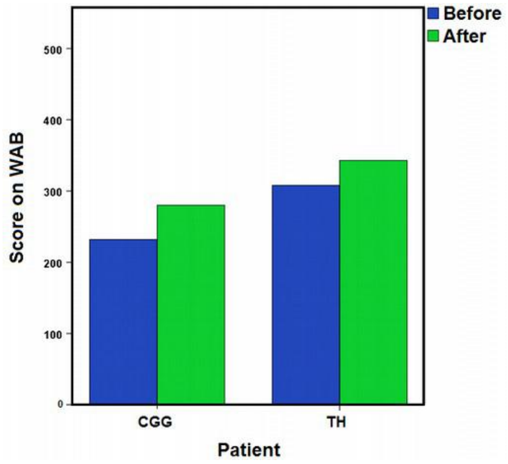

Figure 5. *Results from pre- and post- WAB for C.G.G. and T.H. Blue bar: pre-evaluation score, green bar: post-evaluation score.*

The patients were asked to complete excerpts from the Western Aphasia Battery (WAB) before and after the intervention (see Protocol). The excerpts included the evaluation of "Spontaneous Speech" (20 points), "Auditory Verbal Comprehension" (200 points), "Repetition" (100 points), "Naming" (110 points) and "Reading" (100 points). Accordingly, the maximum score which could be achieved equaled 530 points. Both patients scored higher in the post evaluation than in the pre-test (see Fig. 5). Results from WAB prior to the intervention show an increase for C.G.G. and T.H. by 20.7% and 11.4% respectively. C.G.G. scored 232 points and his result increased to 280 points after the intervention sessions. T.H. had 308 and 343 points before and after the intervention.

3.2 Data from the System

The mean RTs from every session was reported and compared throughout the five days of the intervention for C.G.G and T.H. (see Fig. 6). The reported data shows that the RT of C.G.G. decreased from 22 seconds (first day) to 10.75 seconds (fifth day), that is, by 51.1%. Similarly, in case of T.H. the RT also decreased from 22 (first day) seconds to 6.3 seconds (fifth day), that is, in 71.4%.

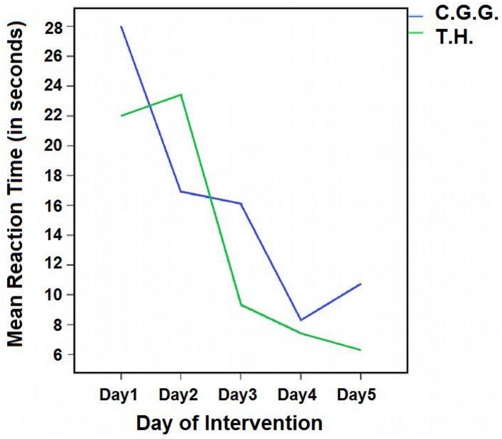

Figure 7. *The total scores obtained during every session by the two patients. Green: the score of T.H.; blue: the score of C.G.G.*

We define a failure as an event when a patient passes an object different than the one which was requested by the opponent. We believe that such behavior is caused by either confluent interaction with the system or a misunderstanding of the requested object. Over the period of the intervention the number of FTs in case of C.G.G. decreased by 62.5% and in case of T.H. it decreased by 55% (see Fig. 8).

We considered the amount of objects selected representative for the fluent interaction with the system. In both patients the quantity of objects selected per session increased. C.G.G. selected 24 objects during the last session which was 3.8 times more than during the first day (see Fig. 9). The number of selected objects in case of T.H. was 2.2 times higher on the last day of the intervention. The patient selected 9 objects during the first and 20 objects during the last session.

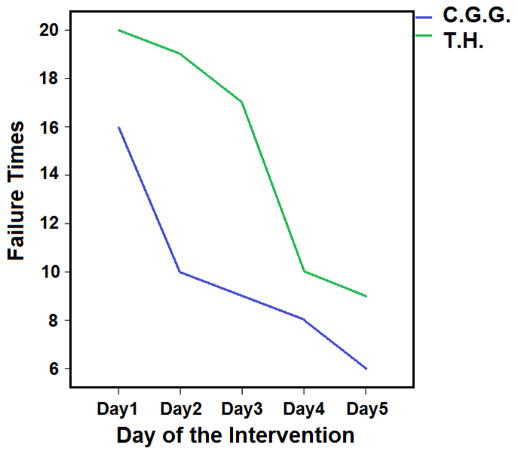

Figure 8. *The number of Failure Times in every day of the intervention for the two patients.Failure times: the times when a patient gave an object different the one requested. Green: the number of FTs for T.H.; blue: the number of FTs for C.G.G.*

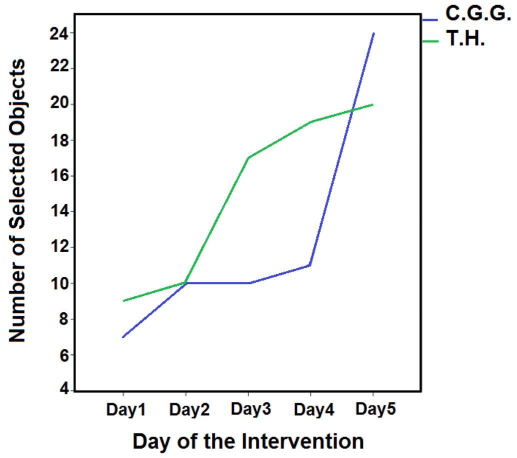

Figure 9. *The number of objects selected during every session by the two patients. Green the number of objects selected by T.H; blue: the number of objects selected by C.G.G.*

The System Evaluation Questionnaire was distributed after the period of the intervention. It consisted of 16 questions which regarded patients' opinion on the system, its usability, functionality, design. The patients were to declare to which extend they agreed with a given statement on a 7-point Likert scale (see Protocol). The maximum score was 112 points from which C.G.G. scored 89 (79.5%) and T.H. 109 points (97.3%) respectively.

4. CONCLUSIONS AND DISCUSSION

In the present study we designed and developed a VR based language rehabilitation tool by integrating ILAT's request LAG to the RGS, and tested the system. The principal purpose of the initial pilot study was to validate the system and to learn whether a virtual adaptation of the Intensive Language Action Therapy into RGS can trigger positive changes in the linguistic behavior of Broca's aphasia patients. The gathered results suggest that both subjects learnt how to interact with the initial model of RGS-ILAT and they were satisfied with the system. Since Broca's aphasia patients do not suffer comprehension deficits (LaPointe, 1990), FTs were mainly associated with the fluency and facility with which the users interacted with the system. After the intervention, the FTs in case of both C.G.G. and T.H. decreased. These results show that both patients got gradually acquainted with the system. The patients could interact more easily within the VR scenario, manipulate the objects and, as a consequence, play with more fluency. Additionally, the results from the SEQ were highly promising. C.G.G. and T.H. evaluated the system for 89 (79.5%) and 109 points (97.3%) respectively. The assessed attributes included facility, comprehensibility, fluency, effectiveness, the range of practiced vocabulary, entertainment and more. The questionnaire was also testing whether the patients felt entertained, motivated and satisfied while interacting with the system. To the statement "I would like to have the system at home" both patients strongly agreed. No further improvements were suggested by the participants. After having analyzed the overall results from the study, it can be argued that the approval and acceptance of the system was high. The reported positive changes in pre and post both WAB and LAG suggest that C.G.G. and T.H. improved their core language skills as well as communication skills. Since the RTs decreased in case of both patients over the period of the therapy, it may be concluded that both patients improved their language behavior within the 5-day intervention. Moreover, in both patients, the number of scored points in the game rose or remained unchanged through the sessions, which accounts for the increase in fluency.

One of the limitations of the present study was the lack of implementation of a precise hand-tracking system, which would allow for the simultaneous use of language and motor actions (e.g. holding the card while requesting the represented object), highly encouraged by ILAT. Moreover, we have not yet implemented the action-planning LAG, as suggested by the original protocol (Difrancesco et al, 2012). To reliably compare the RGS-ILAT with the original therapy we need to include increasing number of objects that would amplify the range of the lexicon used, by introducing words of different frequency, minimal pairs, semantic categories, and multi-feature objects. Although present results might have been additionally influenced by other factors than the intervention, such as the natural recovery processes, motivation, or personal attitude, the positive outcome encourages us to further develop and test the system. Since only two subjects participated in the study and the period of the intervention was limited to five days, we are not yet able to compare our results to those of the original therapy To fully validate the RGS-ILAT system we will therefore conduct a follow-up study with an increased number of subjects and a higher intensity of the intervention, to be able to compare our results with those of a similar non-VR, and investigate whether the present system is more, less or equally effective. This will also shed the light on whether the positive rating of the proposed therapy is influenced by the novelty effect. Based on previously discussed results, the gathered feedback, as well as limitations we will provide the present ILAT-RGS with substantive technological advancements and evaluate the system in order to better understand the potential of the virtual reality based language rehabilitation therapies. The reason for proceeding with the enhancements of the RGS-ILAT system is to provide aphasia patients with an effective language rehabilitation tool which could be utilized as an additional reinforcement to the conventional therapy, or its continuation.

Acknowledgements: We would like to thank Dr. Pulvermuller for the encouragement and support as well as the stuff from the Hospital de La Esperanza in Barcelona who allowed for conducting the study. Finally, we would like to specially thank the patients for being so kind and contributing to the following study. This work was supported by the EU project eSMC (EC-FP7/270212).

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Speech development and therapy using the Kinect

S Frost, R J McCrindle

School of Systems Engineering, University of Reading,
Whiteknights, Reading, UK

s.frost@microsoft.com, *r.j.mccrindle@reading.ac.uk*

www.rdg.ac.uk/sse

ABSTRACT

The use of computers and technology to treat patients with developmental problems or rehabilitation needs is an emerging field. Implementation of such treatment methods however has not traditionally been easy, requiring expensive equipment, significant programming experience and the time of trained medical professionals. The release of gaming systems with natural user interfaces has opened up new possibilities for creating home based therapy and rehabilitation systems that are more engaging, affordable and customisable to individual needs. This project leverages the high quality voice and facial recognition capabilities of the Microsoft Kinect natural user interface, and affordable hardware, to provide an interactive speech therapy application that can be used by patients in their own homes, whilst also collecting metric data for remote monitoring by medical professionals to ensure that engagement with, and appropriate progression of, treatment is occurring.

1. INTRODUCTION

In the UK, 2.5 million people, and in the US 7.5 million people, have a speech or language difficulty (RCSLT; NIDCD). Speech and language therapists assess and treat speech, language and communication problems in people of all ages to help them communicate better. Speech and language therapy is an extremely diverse field, treating problems in adults and children that may have been caused by a wide range of developmental conditions, diseases or disabilities such as stroke, learning disabilities, neurological disorders, head injury, deafness or dementia (Patient.co.uk). Individuals with developmental issues may require the assistance of trained therapists to promote correct development of speech, whilst sufferers of conditions such as stroke, and other brain traumas or diseases may require speech therapy in order to return their ability to speak properly.

As the field is diverse, methods of categorising different types of speech problems have been developed across medical practices which include for example (Stroke Association, 2011):

Aphasia which covers problems related to understanding or expressing speech and language correctly, and which is subdivided into component groups including Broca’s (expressive) aphasia, Wernicke’s (receptive) aphasia and global aphasia. Receptive aphasia is the inability of a person to understand language, or to make sense of the words that one is hearing and their meaning. Expressive aphasia is the inability to speak words, or determine the correct word to use when speaking, for example, jumbling sentences or mixing up similar words.

Dysarthria which covers problems forming particular sounds with the mouth during speech, due to weak muscles or the inability to properly control the muscles in one’s mouth. This can often lead to others having difficulty understand a person as their speech may be slurred, imprecise or quiet. It may be developmental as a result of brain changes before or during birth or acquired as the result of a head injury or medical condition such as stroke or Parkinson’s disease. Dysarthria is often present in patients who also suffer from expressive aphasia.

Dyspraxia/apraxia which refers to the inability to move the muscles required for speech in the correct sequence to form words and sounds properly. This is often shown by a patient’s inability to correctly order mouth sounds in long, compound words especially when component sounds are similar, by making inconsistent mistakes when speaking, or by incorrectly varying the rhythms, stresses, and inflections of speech that are used to help express meaning.

Each of these different types of speech disorder has differing common methods of treatment and associated activities and exercises that patients perform to help combat their condition (Deane et al, 2001). These can range from flash cards, reading exercises or vocalisation tasks which are often performed at home, and then repeated regularly with therapists to determine how a patient is progressing. Since these activities are often formulaic and well defined, they provide an appropriate target for simulation within computer-based applications and/or support for speech and language therapists. However, to correctly develop and apply software that is useful to therapists and beneficial to patients the appropriate methods, reference models and tools must be understood so that the software produced can be most effectively developed and exercises selected to match individual patients' therapy needs (Glykas and Chytas, 2004; Schröder et al, 2007).

2. SUPPLEMENTING SPEECH THERAPY THROUGH TECHNOLOGY

The last decade has seen a growth in the number of computer-based systems and specialized speech recognition software to supplement treatment of patients who have speech disorders stemming from developmental problems, or conditions such as post traumatic brain injury or stroke. AUDIX, for example, is a knowledge-based multimedia system that provides auditory discrimination exercises via a mix of visual stimuli (words, pictures) and audio (voice) clips to adult aphasic patients to help them discriminate between minimal pair sets of words (Grawemeyer et al. 2000). Another multimedia system designed for aphasic patients is the IMITATE system which has a pool of treatment stimuli consisting of audio-visual recordings of 2636 words and 405 phrases of varying complexity spoken by six individuals differing in gender, age and race (Lee et al. 2009). A Chochrane review of speech and language therapy for aphasia following stroke has been carried out by Kelly, Brady and Enderby (2010) and Dean et al (2001) have undertaken a comparison of speech and language therapy techniques for dysarthria in Parkinson's disease.

Saz et al. describe an interactive tool and speech recognition system to facilitate language development skills for children and young adults aged 11-21with neuromuscular disorders such as dysarthria (Saz et al. 2009), and Umanski et al (2010) report a voice-based rhythm game targeted at children with speech motor disorders such as apraxia and dysarthria. Schipor (2014) have developed a framework, PhonEM, and a system, Logomon, designed to help correct children's inability to pronounce words due to dyslalia taking into account their emotional states during the computer based speech therapy sessions. Other systems such as SPREAD (Speech and Phoneme Recognition as an Educational Aid for the Deaf and Hearing Impaired) (Sadural and Carreon, 2012) and a CSLU vocabulary tutor (Kirschning and Toledo, 2004) are computer assisted programmes to aid developmental speech therapy for hearing impaired users.

An increasing range of interactive software packages are becoming available on the market for speech therapy covering common therapy activities and custom therapy pathways including Speech Sounds on Cue (Propeller), StepByStep (Steps Consulting Ltd) and SWORD (University of Sheffield). Some speech therapy software is highly specialized, and only licensable for commercial use meaning that the only access a patient has to the technology is through their therapist or medical institution, however other software packages and games, are becoming increasingly available for purchase (Bungalow Software) including those available for download to tablets and smartphones (Virtual Speech Centre).

As well as development for mobile platforms, recent developments in home and consumer technology such as the Nintendo Wii (Nintendo), PlayStation Move (Sony) and Microsoft Kinect (Microsoft a,b) have brought gaming and interactive systems into many homes. These hardware and software systems can provide novel and unique interactive opportunities, and run on high quality, yet affordable hardware. At present, many of the games and interactive activities available as mainstream entertainment packages are being used informally by relatives or carers of patients with speech problems. Such adoption does however highlight potential issues with this approach, and the software it uses. This is due to existing software and hardware platforms being developed primarily for use by people with no disability, and hence the input modes, phrases and interaction patterns may not be entirely suitable for patients with speech therapy needs, potentially causing negative reinforcement, incorrect pronunciation or repetition. Whilst there has been some specialised development of the Kinect for speech therapy applications (Mravak et al. 2013; Lanz et al. 2013) the field is still at an embryonic stage with the number of games developed to support speech therapy being far less than those developed to support motor rehabilitation.

The aim of this project has been to develop, using the Microsoft Kinect natural user interface, an engaging interactive therapy application prototype that can be deployed using cheap accessible hardware into patients' homes in order to supplement existing speech therapy plans. The developed application provides a number of activities, presented in an interactive and engaging manner, designed to replicate the functions of common therapy methods. While a patient is undertaking these activities, data can be collected and stored remotely about their performance, choices or other appropriate metrics. Provision of a local interface allows a therapist or carer to steer the session and to monitor a patients responses whilst they are undertaking the activities. Metric data from the session is available through a second application which visualises the data for medical professionals to review.

3. REQUIREMENTS

Based on reviews of the literature, product evaluations and discussions with speech therapists and language development experts a number of key considerations were identified as being important, in addition to incorporation of appropriate therapy exercises, for a Kinect based speech and language therapy system:

3.1.1 User Engagement: whilst there are many software packages available whose interactive pathways and activity style have been purposefully designed to help with speech problems some appear to have been designed with only the medical outcome in mind, providing a bland and uninspiring interface to the patient. This can cause the patient to disengage from the application, or begin neglecting its use, subsequently not gaining the full benefit of the software. Meetings with the therapists confirmed that one of the most challenging tasks for patients undergoing therapy for speech issues was maintaining engagement and interest in the exercises whether traditional or software based. Existing applications are often fundamentally useful, but can sometimes appear as outdated and visually or interactively unappealing when used for extended periods of time. This was especially true for younger patients, but was also identified as a problem for adults.

3.1.2 Suitability and ease of use in the home: provision of speech therapy in the home environment is useful in terms of providing continuity of therapy between face-to-face sessions and in terms of engagement. However, some current software has complex support requirements, and may be difficult to use for those without sufficient computer skills. The complex nature of the software can also require therapists to be present to operate the software, or the equipment used, not only to ensure the patient can access the software, but to ensure the correct course of treatment takes place.

3.1.3 Affordability: some of the current speech therapy packages are expensive and may require multiple home user licenses, and professional or clinician licenses which can become prohibitively expensive.

3.1.4 Customization: existing applications are often without the ability to freely and easily customize or tailor the exercises being undertaken to a particular patient or their condition. This may mean that the usefulness of these packages is diminished for border case patients or those with atypical symptoms.

3.1.5 Feedback: existing applications also often lack the ability to play back sample sounds and provide feedback as to the accuracy of the speech recognition or sound processing. Some applications incorporate videos to demonstrate proper mouth shape, but none appear to measure mouth shape as part of the feedback.

3.1.6 Metrics: data collection and patient progression measures are present in some applications in a very simple form, but often require the purchase of more expensive professional versions of the application. In the best cases timings and exercises are measured but there tends to be a lack of medically useful information recorded.

*3.1.7 Integration: w*hilst existing software products offer appropriate features, they tend to focus on one aspect of the therapy process. Few currently available packages integrate speech exercises, metrics visualisation and storage, and real-time customisation in one integrated package.

These considerations stemming from the literature and product reviews and discussions with therapists demonstrate the need for a low cost application that is capable of interpreting speech, and providing feedback on the quality and completeness of spoken words.

4. OVERVIEW OF THE SPEECH DEVELOPEMNT AND THERAPY SYSTEM

4.1 Microsoft Kinect

The Microsoft Kinect is a natural user interface device that incorporates both video skeletal tracking and voice recognition technologies. It is able to interface with both the Microsoft Xbox games console and with personal computer devices. Version 1 of the sensor enables 20 joints and 40 facial points to be tracked, whilst the recently launched Kinect sensor version 2 enables 25 joints plus open/closed hand states to be recognised as well as additional facial expresssions.

The voice recognition subsystem of the Kinect interface is a quad microphone array with built in low level pre-processing, designed to optimise the system for speech recognition. Microsoft provides an API which allows open use of a number of voice recognition libraries, including a specific library for the Kinect and the standard Microsoft Windows dictation library. This allows the Kinect voice recognition system to work in a number of environments for different purposes, depending on the library selected.

4.2 System Overview

The system developed is comprised of multiple components organised into four separate applications with different therapy related functions, running on distinct devices, and communicating over a local TCP/IP network. The ‘Client Application’ is the games-based programme that delivers the speech therapy and with which the patient interacts; the ‘Data Application’ is the data storage application that records and stores the metric data from each game session for a particular patient; the ‘Supervision Device’ is the interface a therapist uses on a tablet or smart phone to control the therapy exercises delivered to the patient; and the ‘Data Application Front End’ visualises the data stored in the database in order to display the metrics requested by the therapist. An overview of the system architecture is shown in Figures 1 and 2.

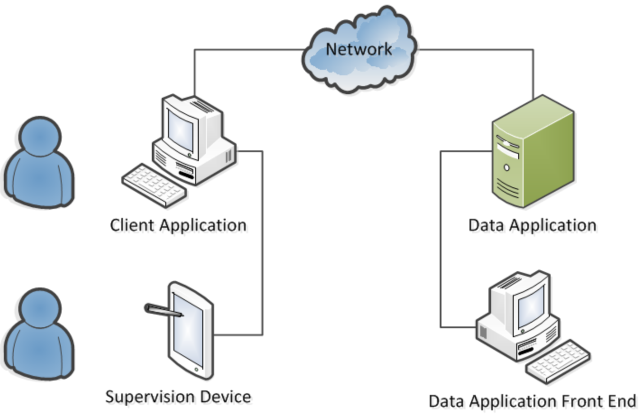


Figure 1. *Distribution and network diagram.*

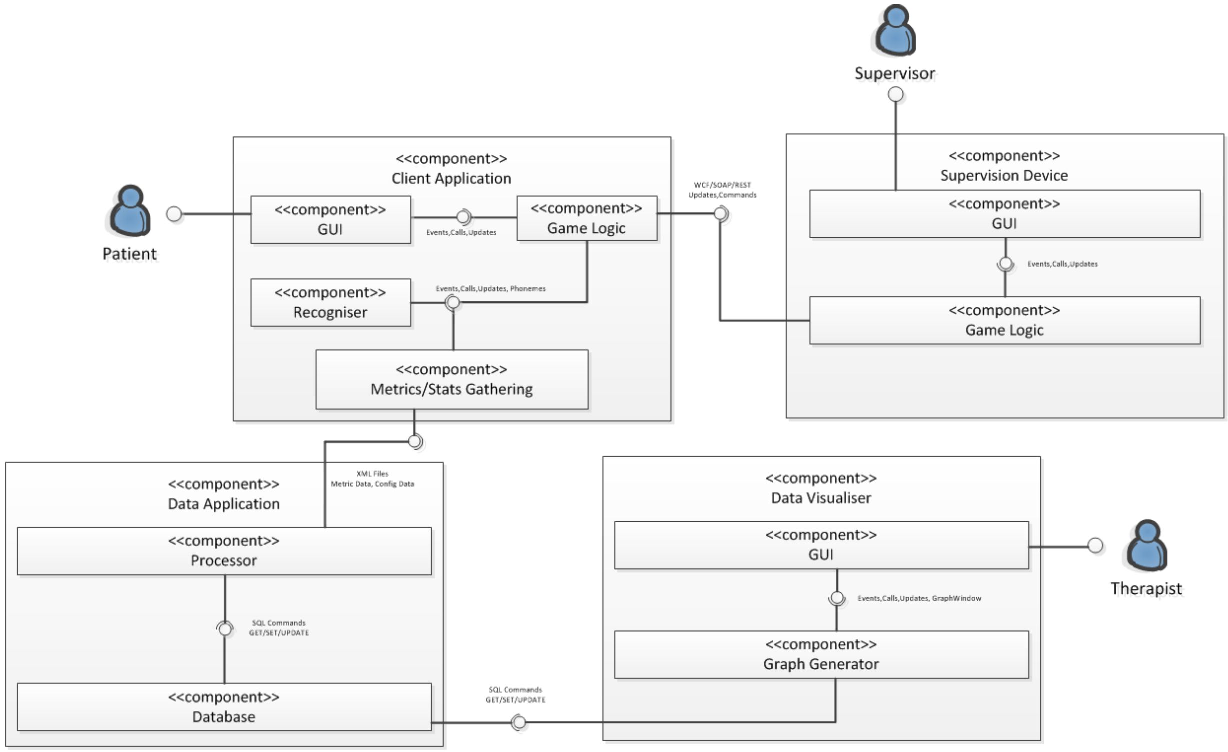


Figure 2. *System architecture diagram.*

4.3 Interactive Element

A prototype application has been developed to help with a patients practice regime, targeting users who as part of their therapy must work through training sets of words such as those shown in Figure 3, in an effort to correctly pronounce each element of the word. Traditionally this is a repetitive task, which can be arduous to complete. To combat this, the prototype system presents the words in the form a game, in which the user collects points by pronouncing each segment, and then the entire word. When a certain number of points have been collected, they can be submitted to a leader board, or used to access games or activities. This is intended to give the user incentive to complete each word set.

The carnival flash card game shown in Figure 4 is a GUI (Graphical User Interface) component that presents users with words, broken into phonetic chunks as part of a fairground environment. These light up as the computer detects correctly spoken phonemes to show the user how they are progressing with pronunciation of the word. A power bar is also displayed on screen to show how correct an attempt is at any time. If the phoneme is correct, the application lights up a bar on the block, leading to the prize, in much the same way as a "strong man" machine works at a fairground when it is hit with a mallet. This is intended to provide the user with feedback and capture their attention as they work to complete the game.

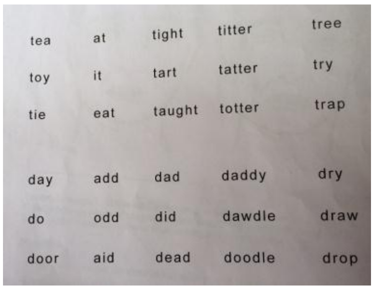


Figure 3. *Training set of words.*

Figure 4. *Interactive Game Interface.*

4.4 Metric Gathering

In order to ensure that the application is providing correct and effective support to the patient, it is capable of collecting and reporting data to the speech therapist about each session the user undertakes. Currently, a large amount of metric data is collected relating to the progression of the user through each part of each word, with regards to the time they take, their accuracy of pronunciation and the percentage of words in the training set completed. It is intended that the data visualised will be further customised to provide precise and targeted data relevant to individual patients or plotted against identified norms, however actual data sets have still to be finalised in conjunction with the medical professionals and extensive user testing has yet to be completed.

As data is collected it is reported to a central server, where it is analyzed and moved into a database which keeps track of each user's session details. This database is intended to be private, and only accessible by doctors and therapists who will use it to record their level of engagement with their therapy programme, track the progress of a patient, and from the result determine the most appropriate course of therapy.

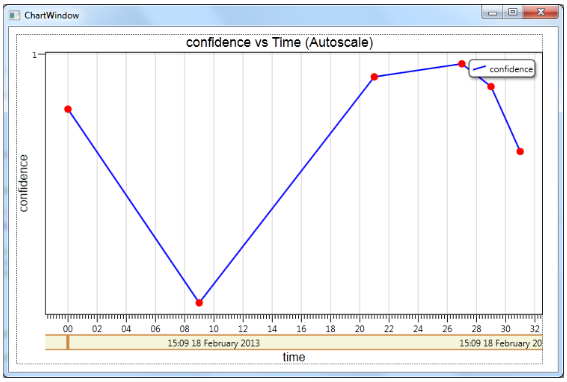


Figure 5. *Example Metric Graph.*

A small client program collects the data, and allows it to be browsed and graphed, or used to generate reports depending on the type of data as shown in Figure 5.

4.5 Mobile Device Supervision

The interactive environment also provides an interface, developed as part of the project, which is available to view on a smartphone and/or tablet device (Figure 5). The application delivered as part of the prototype allows a therapist (or carer) to connect to the session, and see past and current words and upcoming words and segments, or if they wish add custom words and segments while the application is running, without interrupting the ongoing interaction. This inclusion allows close supervision by a carer or therapist to steer the course of treatment, for example by focussing on particular words, preventing repeat words, or skipping words which present particular difficulties.

Figure 6. *Supervisor Device Application.*

4.6 Facially Assisted Recognition

One of the major hurdles for people suffering from speech related ailments is often their inability to perform sufficiently distinct mouth shapes to pronounce a word correctly. Speech therapy exercises often require a patient to practice these mouth shapes based on paper images like those shown in Figure 7. The Microsoft Kinect skeletal and facial tracking features provides the ability to recognize the facial structure of someone who is in close proximity to the sensor and overlay a map of triangular shapes on the screen representing the major features of the face as shown in Figure 8. These features can then be automatically compared to the correct mouth shapes either with or without words being uttered.

Figure 7. *Sample Speech and Language Therapy Exercises.*

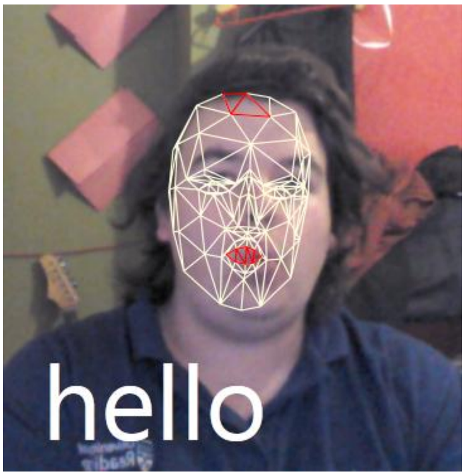


Figure 8. *Facial Recognition Map.*

This mapping is also used to assist the recognition engine in correctly determining broken speech. The mouth shape given by the facial recognition is analyzed and the average height and width of the set of triangles representing the lips measured. By comparing this data to the suggested recognition semantic elements, the application can determine if one of several basic mouth shapes is being employed, and infer if it is compatible with the suggested recognition. This provides an extra confidence metric both to ensure the correct operation of the interactive game, and as an additional logged metric.

4.7 Deployment

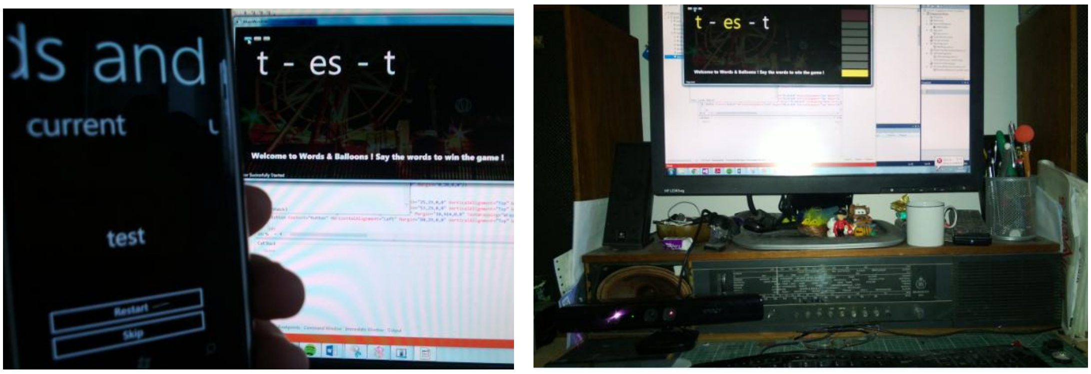
The client interactive application has been developed in C# using the Windows Presentation Foundation. It is intended for use with a Microsoft Kinect for Windows device, and as such makes use of the full C# API. The application is fully unthreaded, and capable of managing a multi Kinect aware environment.

The application exposes a Windows Communication Foundation RESTful SOAP service that allows a mobile device to connect and manage the ongoing session from within the same wireless or wired network. This service is intended for use through the developed Windows Phone application, but could be invoked by any Web capable device.

The application has been developed to run under Microsoft Windows 7 as this provides the widest base of hardware requirements possible for the system, to ensure low cost deployment into patients' homes.

5. TESTING

The prototype application has been tested against a partial list of possible phonemes, with full debugging information displayed on the screen and recorded into the test results manually. The setup for this test, at a standard desk with the development hardware can be seen in Figure 9.



Figures 9. *Client Application Prototype Testing.*

One key test undertaken was the system's ability to recognise spoken phonemes, using both recognition methods (audio and video). This test was undertaken using a set of the most common phonemes in the test word vocabulary. Each phoneme was repeated 10 times, and the output from both recognisers recorded. The correlation between the audio recognition, and whether or not the camera identified the mouth shape as being correct are shown in Figure 10. These results are currently being further analysed and the models adjusted.

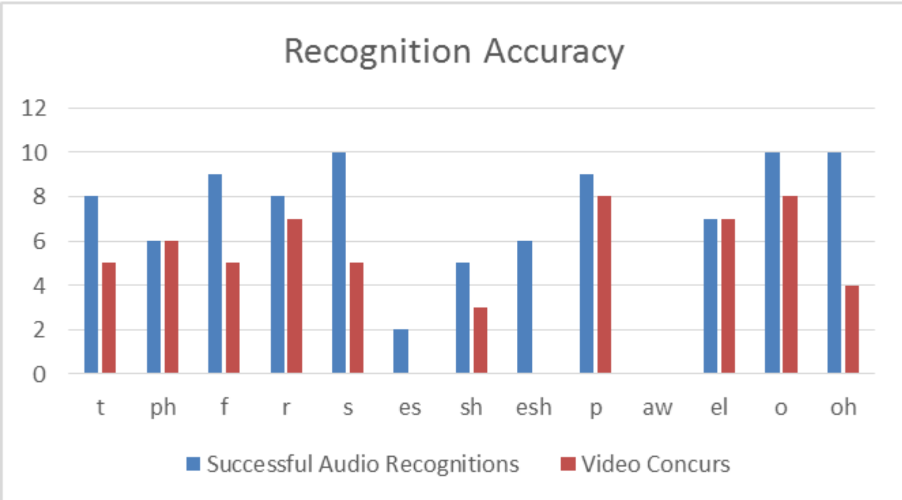


Figure 10. *Audio and video recognition accuracy.*

The application was further tested to ensure that the therapist's device commands were successfully carried out by the game engine. This was setup using a private WiFi network at the development system, with the network settings typically emulating those that would be found in most homes with modern broadband connections; the connection can be seen in Figure 11.

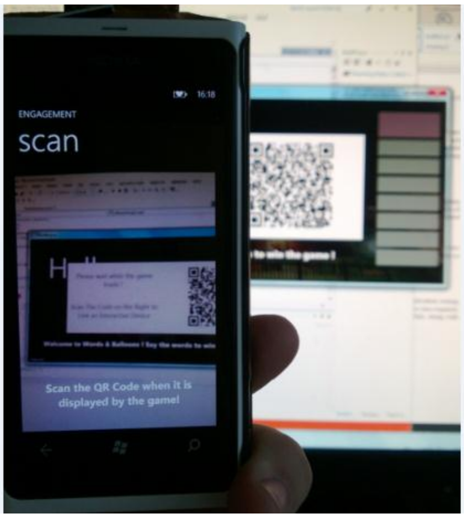


Figure 11. *Testing of the supervisory interface.*

6. CONCLUSIONS AND FURTHER WORK

Overall this project has succeeded in developing a targeted proof of concept application utilising modern consumer technology for assistance with the treatment of speech disorders in the home. This is extending the scope of the Kinect for speech rehabilitation purposes. The project prototype has also demonstrated the concept of remote therapy through being able to collect session metrics for real-time monitoring of the session and/or post session analysis. Whilst there is still much further development and testing to take place and adjustment of the system to further increase accuracy, the system has provides a framework on which subsequent developments can take place. These include:

- Remote Customization: development of a modular system that treats each therapy mode as a game level will provide the ability for therapists to remotely load new modes and activities. This will allow extended periods between one-to-one treatment visits in the home whilst still providing access to tailored therapy for patients.
- Visual & Audio Logging: the existing prototype makes use of the high quality voice recognition features of the Kinect. These, and the high quality camera could be used, with the patients consent, to take audio logs of their speech and visual logs of their mouth movement to assist therapists to accurately monitoring therapy sessions remotely. These logs could be stored and uploaded through the existing architecture, and even furnished with real time data overlays.
- Data Warehousing & Analysis: re-development of the systems metric database to use a data warehousing technology such as Microsoft CUBE (Microsoft c) would provide the ability to track trends and common patterns in patient therapy response data. This data could then be used to help future patients, and customize the interactive software to further directly address patient needs.
- Other Medical Targets: due to the modular nature of the application, and the use of the Kinect sensor, the prototype application could theoretically be used to provide treatment for a more diverse range of ailments including physically limiting problems. For example muscle damage which requires exercise sessions which could be monitored and analyzed for correctness by the Kinect skeleton tracker, and relayed to relevant medical staff, or personal trainers.
- Further Discussions, Development and Tests: following on from this initial proof of concept we are intending to interact further with speech and language therapists, to develop more games and to conduct further trials with regards to the accuracy of the system and its use as a therapy aid. We are also investigating how much more accurate the Kinect version 2 sensor is than the first generation sensor that was used for this development.

Acknowledgements: We would like to thank the speech therapists and linguistics experts for their valuable comments during the development of the system.

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Design and usability evaluation of an audio-based college entrance exam for students with visual disabilities

J Sánchez[1], M Espinoza[1], M de Borba Campos[2]

[1]Department of Computer Science and Center for Advanced Research in Education (CARE),
University of Chile, Santiago, CHILE

[2]Faculty of Informatics – FACIN, Pontifical Catholic University of Rio Grande do Sul – PUCRS
Porto Alegre, BRAZIL

jsanchez@dcc.uchile.cl, maespino@dcc.uchile.cl, marcia.campos@pucrs.br

[1]*www.dcc.uchile.cl,* [2]*www.pucrs.br/facin*

ABSTRACT

The purpose of this research was to design, implement and evaluate the usability of a digital pilot system that adapts the Language and Communication subject section of the PSU (Chilean college entry exam), allowing for equal and autonomous participation by learners with visual disabilities in the college selection process. The study was carried out in two stages during the years 2010 and 2012. The pilot project was carried out in December of 2010 in three different regions of Chile, at the same time as the regular process for taking the PSU. Based on the initial results from 2010, the system was redesigned, implemented and evaluated in order to create the final version. The results for the final version of the tool designed demonstrate a high level of usability. This work provides a detailed analysis and discussion of the results obtained in 2012, as well as future directions regarding the issue at hand.

1. INTRODUCTION

According to the WHO 2014, there are approximately 285 million people in the world with visual disabilities, of which 39 million are blind. The geographic distribution of this disability is not uniformly distributed throughout the world, and approximately 90% of people with visual disabilities live in developing countries.

In Chile, the results of the CASEN 2011 survey indicate that 6,3% of the population has at least some degree of disability, in which the most frequent disability corresponds to blindness or visual difficulties (15,4%), even when using glasses (Ministry of Social Development, 2014).

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 in school, among the disabled population this shrinks to only 8.5% (Senadis, 2004).

In order to implement educational integration of this population 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, encouraging higher classroom attendance, participation in the learning process, and the learning of expected lessons for all students, with a special focus on those with special educational needs, whether of a permanent or temporary nature (Mineduc, 2012).

In the admissions process for Chilean universities (directed by the council of rectors), a standardized testing instrument called the University Selection Test (PSU, for its Spanish acronym), is utilized in order to measure student knowledge and skills in various educational subjects: Language and Communication, Mathematics, History and Social Science, and Science. The procedure for the use of this instrument traditionally involves a paper and pencil based test, which restricts the options for people who are blind to be able to participate in the regular testing process.

There is evidence of initiatives to integrate participants with visual disabilities into normal test-taking processes from other countries. Kaczmirez and Wolff (2007) presented guidelines for the design of self-administered surveys for people with visual disabilities including people who are blind within a mixed mode approach (paper-based, Braille-based, and 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 Japan, work has been done incrementally on a system of evaluation for users who are newly blind and also have problems with dyslexia, so that they are able to take the National Center Test for University Admissions (Fujiyoshi and Fujiyoshi, 2006; Fujiyoshi et al, 2010, 2012). In India, special science exams in physics, chemistry, biology and mathematics were announced for 2012 and 2013 (Higher Education in India, 2011). These tests are adapted for students with visual disabilities by excluding visual elements such as diagrams or graphics. In China in 2002, the possibility was opened for students who are blind to be integrated into the regular process for the national university entrance examination (China, 2002). In Brazil, Article 27 of Decree N°3.298 (Brasil, 1999) defines that higher education institutions should offer adapted tests as well as the necessary support when previously requested by a student with disabilities, including additional time to take the tests, in accordance with the characteristics of the particular disability. For test takers who are blind, universities even offer the use of handheld magnifying glasses, tests with enlarged print, tests given in Braille, and even tests given orally by special aids trained for this purpose. Despite this advanced level of special attention, the test taker who is blind does not take the test in the same place along with the other candidates, as they require special test taking spaces, and sometimes even take the exam on a different date and at different times as the normal exam. In addition, it may be difficult for test takers who are blind to manage the Braille test (imagine having to read a 20-page test in Braille, for example, and the difficulties related to asking for help on specific test questions and reviewing one's answers), to understand the pronunciation of readings for translation into another language, or even to describe the images printed on the test.

In this context, the purpose of this research was to design, implement and evaluate the usability of a digital pilot system that adapts the PSU in the subject of Language and Communication, allowing for equal and autonomous participation by people with visual disabilities in the college selection process.

The study was carried out in two stages during the years 2010 (Sánchez and Espinoza, 2012) and 2012. The pilot project was carried out in December of 2010, at the same time as the regular process for taking the PSU. This pilot was performed in three different regions at the same time. Based on the initial results from 2010, the system was redesigned, implemented and evaluated in order to create the final version. This work provides a detailed analysis and discussion of the results obtained in 2012, as well as future directions regarding the issue at hand.

2. AUDIOPSU SYSTEM (FINAL VERSION)

From the beginning, the design of the system considered: (i) No special spatial requirements needed to take the test; (ii) Development of an adapted, standardized, knowledge measurement instrument; (iii) No student aides needed to take the test; and (iv) Provision of the same advantages that sighted people have in being able to navigate between the various test questions (Sánchez and Espinoza, 2012).

The AudioPSU System was first presented in (Sánchez and Espinoza, 2012). The system consists of an adaptation of the Language and Communication PSU, which is organized into 3 different sections: I) Knowledge of basic concepts and general language and communications skills, II) Text production indicators, III) Reading comprehension.

There are four different kinds of questions with varying specific formats included in the PSU Language and Communication subject 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 format that is 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.

The interaction with AudioPSU for the user with visual disabilities takes place through the use of a numpad, allowing users with visual disabilities to navigate between the various interfaces provided by the software. 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. Finally, the system provides information regarding navigation through the text in order to resolve the questions through text-to-speech (TTS), which can be heard through stereo headphones.

The results of the pilot system implemented in 2010 (Sánchez and Espinoza, 2012) led to a series of improvements, changes and upgrades to the final version of the AudioPSU system, which are described below.

2.1 Software upgrades

The final version of the software works with two different voices, mainly in order to be able to adequately differentiate between the enunciation of the question and the answer choices. The enunciation of a question (as well as the other parts of the test) uses a specific voice for reading the texts. The answer choices are given with a specifically assigned second voice. When the user enters into the answer choice section, the enunciations change to the second voice. When returning to the question, the enunciations change back to the first voice. This change was implemented for all of the questions.

In some cases there are words that are highlighted within the questions, which on the paper copy of the PSU are either underlined or written in bold print. In order to highlight these words, a series of changes were added by writing these words in capital letters and including quotation marks, spaces and commas before and after the words to be highlighted. With these modifications, the reading software (TTS) accentuates the words by increasing the tone of the voice and pausing both before and after the highlighted word. In this way, it is possible to note a break in the flow of the enunciation, clearly demarcating the highlighted word. This change makes it much easier to recognize which words are highlighted in the spoken text.

In addition, an advanced function was incorporated called the matrix navigation mode, which consists of a special way of navigating the questions regarding the management of connectors and writing plans. Essentially, this function serves to navigate the paragraphs or parts of a text as determined by the characteristics of the question.

In the case of the questions regarding the management of connectors, by defect the enunciation of the question presents a text with blank spaces for which connectors must be chosen. In the answer choices different connectors are presented as options to insert into the blank spaces included in the body of the question. In order to activate the matrix navigation mode, the user must be located within one of the answer choices. When this modality is activated, the user can navigate sequentially (backwards and forwards) through the various parts of the sentence, which are determined or segmented based on the position of the blank spaces in the sentence. For example, in a question with two connectors, first the entire first part of the text before the first blank space is read, then the first connector is presented as an answer choice, followed by the following bit of text, next the second connector, ending with the final part of the text. This allows the user to test out the use of the connectors presented as answer choices inserted into the text of the question.

In the case of the questions regarding the writing plan, by defect the spoken text consists of a series of paragraphs including numbered texts (usually between 4 and 6 numbers), and the answer choices present different options regarding the correct order of the text. For example, for a question with 4 paragraphs, one answer choice might be 2-4-3-1. In order to activate the matrix navigation mode the user can listen to the paragraphs in the order proposed by the answer choices sequentially (forwards and backwards). For example, if the answer choice is 2-4-3-1, in proceeding sequentially through the choice the system will read the paragraphs step by step, starting with the second paragraph, moving on to the fourth, from there on to the third, and ending with the first paragraph. In addition, the user can go backwards sequentially in order to reread the paragraphs. For example, if paragraph 3 is being read, the user can choose to move backwards to paragraph 4. This helps the user to read the texts in the order suggested in the answer choice, so that he or she can determine if this order is correct.

2.2 Hardware improvements

The system consists of: (i) A Netbook with the software that adapts the PSU Language and Communication test; (ii) Stereo headphones to provide information to the user (output); and (iii) A Numpad in order to execute the system's actions (input). Each functional key on the numpad has an associated Braille symbol to make it recognizable to users who are blind (Sánchez and Espinoza, 2012).

The numeric keyboard or numpad works as an entry interface for the user. The marks on the functional keys were adapted to incorporate Macrotype and Braille labels together with the sign or letter that corresponds to the given function (see Fig. 1). In this way, a user who is blind or a user with low-level vision can use the same device. This adjustment was made considering the special educational needs of the entire population with visual disabilities, as there are people with low level vision that use Braille, people who are blind who also use Braille, and people with low level vision who use Macrotype. The non-functional keys were blocked (or ignored) by the software, in order to avoid confusion among the users. Another adjustment to the keyboard was the extraction of the "Block Num" key, as this transforms the function of the numeric keyboard, deactivating the numbers associated to the functions utilized in the system.

The keys were grouped together as Navigation, Consultation or Fast Navigation keys according to their functionality:

Navigation Keys:

- *"s" Key*. Move up from a question to the section, from a sub-section to the section, from a group to the section, move up from a question to the sub-section, and from a question to the group.

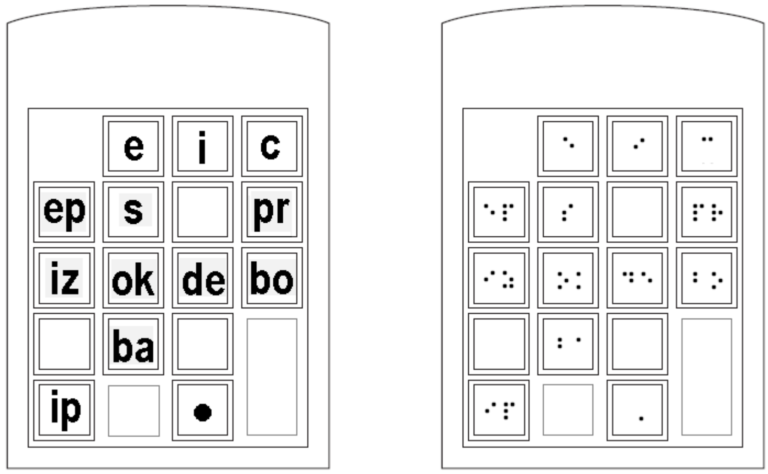

Figure 1. *Keyboard scheme with Macrotype and Braille markings utilized in the AudioPSU system.*

- *"iz" Key.* Move to the left between sections, sub-sections, groups or questions.
- *"ok" Key.* Enter into the desired question, section or sub-section.
- *"de" Key.* Move to the right between sections, sub-sections, groups or questions.
- *"ba" Key.* Go down from the section to a question or from a sub-section to a question, and move down from a group to a question.
- *"ep" Key.* Enter into the matrix mode of navigation between paragraphs of a text. This key will be useful for: (i) navigating between the parts of a sentence using the "iz" and "de" keys (connectors management); (ii) listening to the answer choices of the different statements in order, navigating with the "iz" and "de" keys (writing plan); (iii) at any time it is possible to leave the matrix navigation mode by pressing the "ep" key.

Consultation Keys:

- *"ip" Key.* Start listening to the paragraph, statement, question or answer choice if the user wants to hear it again.
- *"•"Key.* Listen to the information regarding where the user is located in the test.

Fast Navigation Keys:

- *"e" Key.* Listen to the instructions for each section of the test.
- *"i" Key.* Go to the test index for the section or question where the user is located.
- *"c" Key.* Go to the beginning of the test index (Section 1).
- *"pr" Key.* Go directly to the question. A window is opened in which the user can write the number of a specific question (with the same numeric keyboard), and when pressing it again the user will be taken directly to that question. In the case of making a mistake when writing the number, it can be erased by using the "bo" key located below the "pr" key. In order to utilize the numbers, it must be taken into account that the numbers are mapped according to their location by defect on the numpad.
- *"bo" Key.* Erase the question number selected when the function for going directly to a question has been activated.

3. USABILITY EVALUATION (PILOT 2012)

To be able to evaluate the usability of the final version of the tool, a second pilot was performed in 2012. Just as in the 2010 evaluation (Sánchez and Espinoza, 2012). This second evaluation was carried out with the end users who are blind of the system, aiming mainly to validate the tool and to detect any problems and issues with its effective use. This was done in order to be able to compare the results and to measure the effect of the improvements that had been incorporated into the final version. The details of the usability evaluation performed for the 2012 pilot are described below.

3.1 Sample

The sample utilized for the usability evaluation in 2012 was chosen among students who shared the requisite characteristics of being between sophomore and senior level of high school, or being high school graduates in general. The sample was made up of a total of 11 people with visual disabilities. Of this total, 4 were female and 7 were male, with ages ranging from 17 to 55 years old, and all of who are residents of Santiago, Chile. The sample characteristics was equivalent to the one used in the 2010 usability evaluation.

3.2 Instruments

The same user satisfaction evaluation questionnaire regarding the use of the software (Sánchez and Espinoza, 2012) 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 statements 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 helps me to be 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 could 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.

It is important to point out that the 12 statements in this questionnaire were grouped according to 3 dimensions: Satisfaction (1, 2, 3, 4), Control and Use (sentences 5, 6, 7, 8, 9), and Sounds (sentences 10, 11, 12). When processing the results, an indicator for each dimension was calculated, corresponding to the average response given to the questions in each group. The results provide the indicators obtained for each dimension.

Together with this questionnaire, the teacher facilitators of the pilot experience also utilized a Non-Participant Observer questionnaire. 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.

3.3 Procedure

The pilot was carried out in October of 2012. Unlike the first pilot in 2010 (Sánchez and Espinoza, 2012), on this occasion the pilot was performed on a date different from the regular process for taking the PSU. This particular pilot experience was implemented in the Metropolitan Region (Santiago de Chile), using the physical space in the Central Library for Blind People, located in Santiago, during a 4-hour session including usability testings.

The first stage of the procedure consisted of installing the workstations for the users involved in the second sample to utilize the AudioPSU system. Afterwards, the users entered the room, and were requested to sit down at an individual workstation. The composition and distribution of the contents of the PSU Language and Communication subject test on the AudioPSU software were explained, informing the users that the position of the sections was configured in the same way as it is presented to sighted users on the paper and pencil test. The software use instructions were read to the users, and the functionalities available through the numeric keyboard were explained. In this way, the facilitators provided initial support to the participants regarding the use of the system, mainly related to software navigation and exploration of the functionalities using the numpad. This process took 20 minutes. Once this stage had been completed, it was indicated that the time available to finish the test was 2 hours.

In order to support the use of the software, the user had access to supporting guidelines written in Braille or Macrotype (according to the degree of each user's vision). These guidelines provided information regarding the operability of the AudioPSU application, in addition to the buttons used for the interaction. On this occasion, a copy of the test written in Braille was not provided, as happened in the first pilot application in 2010.

In order to evaluate the users' performance in this second pilot, the facilitators in the room used the Non-Participant Observation questionnaire, recording information regarding the experience. In the same way, faced with any questions or concerns regarding the use of the software, the facilitators provided the user with the necessary help in order to be able to utilize the functions of the software.

After the test had been completed, the facilitators proceeded to apply the Software Usability Questionnaire, in order to learn more about the users' evaluations regarding their use of the software.

3.4 Results

The results obtained from the 2012 usability evaluation, based on the application of the end user questionnaires, demonstrated considerable improvements regarding the average scores assigned to the various dimensions in the 2010 pilot (see Table 1). The "Satisfaction" dimension presented an average of 8.4 points (increasing by 1.4 points compared to the 2010 pilot evaluation). The "Control and Use" dimension presented an average of 8.1 points (representing an increase by 0.4 points compared to the 2010 pilot), and the "Sounds" dimension presented an average of 8.5 points (representing an increase of 1.9 points above the 2010 pilot).

In performing a T-Student statistical test of independent samples using the data obtained for both pilots, statistically significant increases in the usability evaluation were found for the "Satisfaction" ($t = -2.177$; $p < 0.05$) and "Sounds" ($t = -2.210$; $p<0.05$) dimensions.

Although the increase observed for the "Control and Use" dimension was not statistically significant, just as in the other dimensions it presented a very high average score on its evaluation. It is worth highlighting that the averages for all three dimensions are above 8 points, within the upper portion of the range of possible values (above 75%), as the scale of evaluation on the end user questionnaire was from 1 to 10.

Table 1. *Results of the end user questionnaire by dimension.*

	Satisfaction	**Control and Use**	**Sounds**
Mean 2010	**7.0**	**7.7**	**6.6**
(Std. Dev.)	(1.64841)	(1.11184)	(2.37603)
Mean 2012	**8.4**	**8.1**	**8.5**
(Std. Dev.)	(1.1307)	(0.70679)	(1.17799)

The quantitative results obtained demonstrate the high degree of the tool's usability. This is clearly shown by the results of the satisfaction category, the positive perception of users regarding control and use of the system, and the high level of interpretability of the sounds.

Regarding the open ended questions section, for the question, "Did you like the software?", certain aspects were especially valued by the users, such as the ease of use, the use of the differentiated voices, the speed of the interaction and the overall clarity with which the software provided information. These aspects point to resources that allow for a higher degree of autonomy when taking tests, and higher levels of ease in understanding test questions and manipulating the test.

For the question, "What did you not like about the software?" some users felt that the tone of the voice and the low level of clarity regarding some words are aspects to be improved in the system. Some considered it important for users to have prior training before using the system. Considering that people who are blind and who use screen readers, for example, are accustomed to certain tones of voice, as are those with access to written content through oral readers, such training would be important for a user who is blind to be able to become accustomed to the tone of voice before taking the test.

When the users were asked what things they would add to the software, they mainly pointed to a speed control option for the voices, and to incorporate a set of different voices to choose from. These are resources that would allow the user to improve or personalize the application in accordance with his or her needs, and according to the nature and specificities of the test questions at hand.

Regarding the questions, "What do you think the software can help you with?", and, "What other uses does it have?", the users expressed opinions related to the fact that the software could be used to take other kinds of tests, and to read electronic documents.

Finally, and just as in the case of the first pilot experience, all of the users agreed that they liked using the numeric keyboard, as it is easy, fast and comfortable to use.

From the non-participant observations it is worth noting the autonomy of the users' general performance. The system's functions were adequately understood by the users, and very few questions were asked regarding the use of the tool, as the users tended to answer their own questions through the support of the system user's manual and the keypad.

In the case of the system usability evaluations, it is worth noting that the pilot experience represented the first time that participating users interacted with the system, which further reinforces the results obtained. This result is similar to that observed for the first pilot experience, as the users identified the buttons of the numeric keyboard without any problems. However, becoming familiar with the functions of the software associated with these keys took some time, and although in the context of the pilot 20 minutes of training was sufficient, in a real life situation it would be far better for users to get to know the tool before taking the actual test.

4. CONCLUSIONS

AudioPSU allows for the integration of users who are blind in taking the PSU test in normal testing rooms with sighted users. This was evidenced in the first pilot experience. This is due to the fact that the system provides information to the system's users only, without producing bothersome sounds or interrupting the work and concentration of others nearby in the test-taking environment. By maintaining the same test-taking format, users felt that they were finally considered capable of interacting in the same way as a sighted student does with the paper based test. In this way, AudioPSU is positioned not only as a tool for equal opportunity and access to the process, but also as a tool that does not require a segregated social environment in order to operate. In addition, specific conditions are not required that impede people who are blind from being included within the regular PSU test taking process. This represents an option that is different from a special process of application of this test, which is currently the only possibility for accessing higher education in the case of people who are blind.

The kinds of adjustments that were made to the pilot systems in 2010 and 2012 for students with visual disabilities were oriented towards changes related to accessing information. This is to say that the adjustments were related to moving from text-based formats to audio-based formats, through the use of software and devices that allow users who are blind to navigate throughout the entire structure of the instrument. In this way, as the sole proposal for modification, a different form of taking the test was proposed.

Without a doubt, one of the advantages of AudioPSU compared to the current system for assisted test taking of the PSU is the degree of autonomy that the software provides to people with visual disabilities. The system provides users with higher autonomy when navigating the test, making decisions, and provides a higher capacity for users to manage the use of time when responding to the questions, according to the audio-reading skills of each user.

Given the initially observed complications in the 2010 and 2012 pilots, related to understanding the operability of the system and the numpad, it was found that it would be necessary to perform prior training with the users, providing accessible material well before taking the actual test. This would allow them to become familiar with the different components of the system and their respective functionalities, similar to practice tests taken by sighted students.

The profile of the users that participated in both pilot experiences consisted of users who were already accustomed to the use of voice synthesizer assistance regarding their experience with computer use. For this reason, the application contains voices that facilitate a comprehension of changing context between different test questions, providing for a more fluid and user-friendly experience with the AudioPSU system.

According to the responses to the open ended questions obtained during the development of the second pilot experience in 2012, only two of the participants had had prior experience taking a practice PSU test. This implies that students with visual disabilities are generally unaware of the test structure, for which reason they do not have much knowledge of the kinds of questions or the extent of the texts involved, among other aspects. This leaves them at a disadvantage compared to their sighted peers.

There are certain requirements for working with AudioPSU, such as the ability to use the Braille reading-writing system. Two of the subjects who participated in the 2012 pilot were not trained in the Braille system, or had forgotten it due to the fact that they had stopped using it. This meant that it took them more time to understand the use of the numpad, which had been re-keyed into Braille. This is relevant due to the fact that the prevailing use of voice synthesizers for people who are blind is not sufficient, and it is necessary to further strengthen more than just one sensory channel in order to obtain and comprehend information.

The positive results of this pilot experience demonstrate the success of the initial adjustments regarding access to the information provided in the test. However, it is necessary to continue studying variables such as the level of reading comprehension, exploration skills and audio skills, among others. In this way, the data obtained is not sufficient to be able to affirm that the audio-based PSU establishes a comparable level of performance between students who are blind and sighted students.

Future work will study the main difficulties and points of advantage that students with visual disabilities experience when learning Language and Communication concepts.

Acknowledgements: This report was funded by the Chilean Fund to Promote Scientific and Technological Development, Fondef TIC-EDU #TE12I1002, the Chilean National Fund of Science and Technology, Fondecyt #1120330, and Project CIE-05 Program Center Education PBCT-Conicyt.

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A participatory design framework for the gamification of rehabilitation systems

D Charles[1], S McDonough[2]

[1]Computer Science Research Institute, School of Computing and Information Engineering.
[2]Centre for Health and Rehabilitation Technologies, School of Health Sciences.
University of Ulster, NORTHERN IRELAND

[1]*dk.charles@ulster.ac.uk*, [2]*s.mcdonough@ulster.ac.uk*

ABSTRACT

In recent years games and game technology have been used quite widely to investigate if they can help make rehabilitation more engaging for users. The underlying hypothesis is that the motivating qualities of games may be harnessed and embedded into a game-based rehabilitation system to improve the quality of user participation. In this paper we present the PACT framework which has been created to guide the design of gamified rehabilitation systems; placing emphasis on people, aesthetics, context, and technology from the beginning of a design and development process. We discuss the evolution of PACT from our previous GAMER framework, which was used to develop a range of games for upper arm stroke rehabilitation with natural user interfaces. GAMER was established to guide the design of rehabilitation games from the viewpoint of a designer, whereas with PACT greater emphasis has been placed on an inclusive design process. We provide a detailed work flow illustration for the use of PACT in the development of rehabilitation systems and provide examples of practical design and analysis tools that improve the quality of workflow in PACT.

1. INTRODUCTION

PACT (People, Aesthetics, Context, and Technology) may be described as a participatory design framework for the gamification of rehabilitation systems. Inclusive participation from the beginning of a rehabilitation design process has been raised as an increasingly important experimental methodology (Gooberman-Hill et al, 2013). Influence from games in the design of engaging rehabilitation software has also received a lot of recent attention (McNeill et al, 2012). Though only a few papers make explicit reference to gamification, e.g. (López-Rodríguez and García-Linares, 2013), there is often an implicit application of simple gamification techniques in the design of bespoke rehabilitation. The focus is often on inclusion of fun user feedback for the completion of tasks, with points, badges, high score tables, and leader boards being typical design patterns used. There is a danger, however, in taking too narrow a focus in the application of gamification to the design of systems. If the design focuses too much on task completion and rewards then there may be an over emphasis on extrinsic motivation, which has less impact on long term behaviour and attitude change. Behavioural change is central to the goals of a well-designed rehabilitation system (Michie et al, 2011). There are several definitions for gamification that vary depending on context but most focused on engagement or motivation (Deterding et al, 2013). For example, the influential company Badgeville states that “gamification is the concept of applying game-design thinking to non-game applications to make them more fun and engaging” (Gamification Wiki 2014). We prefer a broader definition in its application to rehabilitation software; considering gamification as the application of game elements and metaphors, game design patterns, or game technology to the design of systems that can positively influence behaviour, and improve motivation and engagement of people with non-game tasks and processes. We therefore view gamification as taking any influence from games and applying it to a non-game context. In this way a serious game, game-based learning, simple reward based feedback, and a walk in a virtual world can all be thought of as subsumed by the gamification label. In the PACT framework we endorse a system of gamification that can account for variation in motivational factors amongst different individuals and we illustrate this with a workflow diagram.

2. GAMER FRAMEWORK

The GAMER framework (Fig 1.) was developed to guide the design of rehabilitation games (see Burke 2011) for expanded version) that help motivate people to engage with their required exercise regime in the home. It has been successfully utilised in the creation of several webcam (Burke et al, 2008) and augmented reality games (Burke et al, 2010) for upper arm stoke rehabilitation, the latter licensed to US robotics company Myomo in 2011. GAMER was developed after extensive investigation of game design theory from leading game designers and in collaboration with physiotherapy researchers to map therapy goals to tailored, motivating physical gameplay. Our approach was similar to Goude et al. (2007) who also used the comprehensive collection of game design patterns by Björk and Holopainen (2005) as a central design inspiration. GAMER maps keys game design or gameplay elements that are have been identified as being specifically relevant to physical gameplay via a natural user interface to core therapy goals. The framework can be used to aid a designer in creating varying forms of gameplay that emphasises different aspects of therapy by choosing a suitable subset of game design elements/patterns in the design and directing of the choice of interaction hardware. Burke (2011) provides detailed worked examples on how we evaluated GAMER through the design of several rehabilitation games over two case studies.

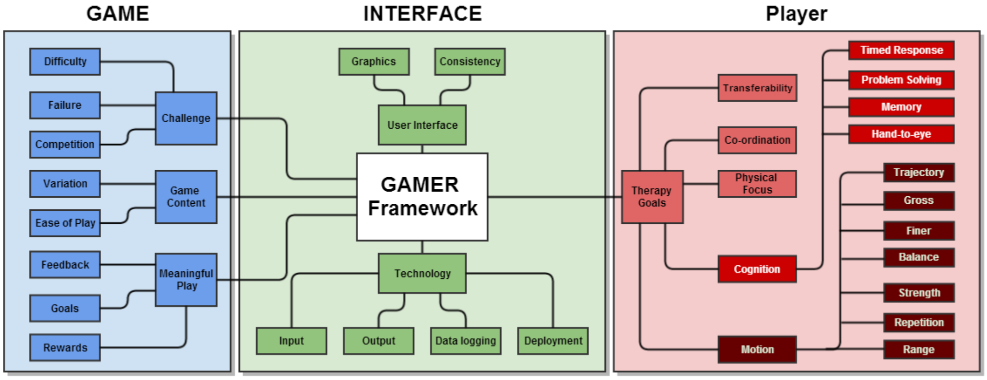

Figure 1. The *GAMER framework is designed to guide the design of rehabilitation games.*

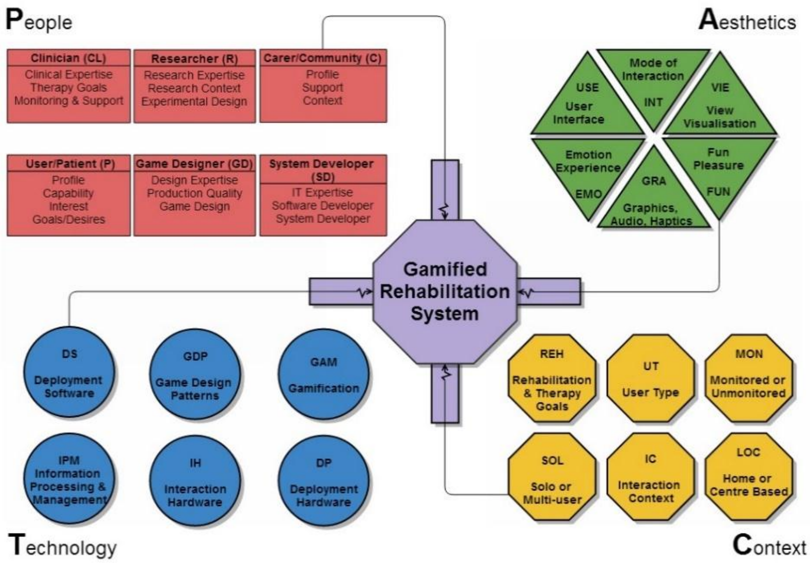

Figure 2. *PACT is a participatory design framework for the gamification of rehabilitation systems*.

3. PACT GAMIFICATION FRAMEWORK

GAMER demonstrated the potential of a structured approach in the design of usable, engaging, and effective rehabilitation games. It is particularly useful in mapping therapy goals to physical gameplay elements and embedding positive reinforcement feedback aesthetics. Our PACT framework evolved from GAMER to increase our focus on stakeholder involvement and place a stronger emphasis on personal motivation of users. The PACT framework (Fig. 2) has four dimensions, People, Aesthetics, Technology, and Context, which form the focus for the design of gamified rehabilitation systems. Unlike GAMER, PACT has an implicit focus on participatory design and involvement with all of the relevant stakeholders from the beginning of a rehabilitation design process. The emphasis on gamification within the PACT framework has a number of significant advances. Firstly, the outcome of a gamification process may not be an obvious game but may simply result in the addition of fun feedback (e.g. points and badges) to a non-game context (e.g. physical movements round the home), could recommend the use of gaming hardware in a non-game context (e.g. digital painting), or the use of game worlds

Proc. 10th Intl Conf. Disability, Virtual Reality & Associated Technologies
Gothenburg, Sweden, 2–4 Sept. 2014
©2014 ICDVRAT; ISBN 978-0-7049-1546-6

to immerse and inspire (e.g. walks with friends in virtual game worlds). Secondly, new advanced gamification approaches can help tailor system design to account for diversity in motivation between different people. The emphasis on behavioural change correlates with other framework designs in the research area (Michie et al, 2011).

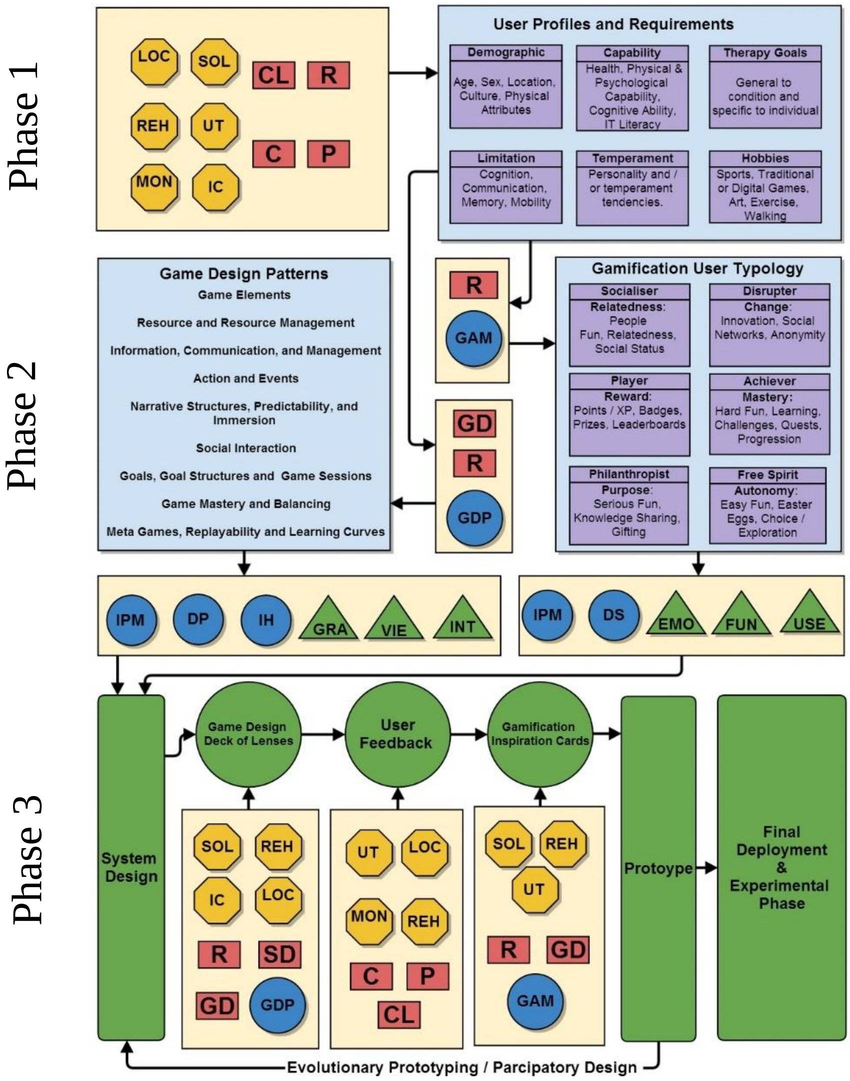

Figure 3. *Sample PACT Rehabilitation System Design Workflow (see Fig. 2 for symbol meaning).*

Figure 3 provides a typical workflow diagram for the implementation of the PACT framework in practice. This resembles the practice that we undertook in the design of our recent upper arm stroke rehabilitation simulations with the Leap Motion controller (Charles et al, 2013). We can split the PACT design process into three phases: Phase 1 is essentially a requirements gathering phase and involves a dialog between clinicians, researchers, users/patients and other stakeholders from the community to establish the basis for system design founded on therapy goals and on specific user and carer needs. Capability of the target group will be accounted for at this stage and temperament models and personal interest of users may be taken into account in order to tailor the design more effectively. Phase 2 is the core design phase and in our new model includes both an underpinning of game design and gamification. In the work flow example shown in Figure 3 we utilise the set of comprehensive game design patterns from Goude et al. (2007) and list the key pattern group headings (NB other references may also be used). The gamification technique that we propose is based on Marczewski's Hexad gamification typology (Marczewski, 2014). This model has its origins in Bartle's player types (Bartle, 1996) and RAMP intrinsic motivation model. Effective gamification can engage individuals by tapping into particular aspects of their intrinsic motivational psychology. The RAMP model outlines four key motivational drivers for people: Relatedness, Autonomy, Mastery, and Purpose. Relatedness equates to sociability, autonomy is about facilitating choice and creativity, mastery relates to the provision of opportunities to learn and improve, and purpose recognises that people are more motivated when they understand the context for their efforts. The Hexad suggests six basic types of user, each being motivated by different intrinisc or extrinsic motivational priorities. The outcome from phase 2 is a system design developed in partnership with key stakeholders. Phase 3 is essentially an evolutionary protyping phase where system software is created and integrated with required hardware. In the workflow example provided we suggest a structured approach for analysis of the design based on the evolving system prototypes. As a 1st stage of evaluation process we suggest rigorous and creative way evaluation of the design by a research and development team using a tool such as Schell's game design lenses to focus on core design topics (Schell, 2008). A 2nd evalution stage involves play and usability testing by users and other stakeholders using techniques developed during our GAMER experiments (or similar). During a 3rd stage of the system evaluation, the gamification system is analysed and redesigned on the basis of user feedback. A structured method such as the use of Marczewski's gamification cards can aid this process. The eventual outcome from phase 3 will be a completed gamified rehabilitation system. The development of the PACT workflow was informed by the recent development of an upper arm rehabilitation systems using a virtual reality based approach and Leap Motion depth sensing controllers for a natural user interface (Charles et al, 2013). Physiotherapy and computing researchers, clinical physiotherapists and occupational therapists from the Northern Ireland Regional Acquired Brain Injury Unit (RABIU) at Musgrave Hospital in Belfast (n=8), and game designers/developers from a commercial company (SilverFish Studios) were engaged in the appropriate phases of PACT (though not patients in this initial proof of concept process). The outcome was very positive and the software is currently under development (PACT phase 3) for use in clinical trials.

4. CONCLUSIONS

In this paper we introduced our PACT framework; a participatory design oriented process for gamifying rehabilitation systems. To explain its use in practice we provided a detailed work flow diagram that included specific suggestions for analysis and design with key stakeholders. Early and structured ongoing involvement of key stakeholders within the system design process is central to PACT. A core recommendation for the realisation of PACT is the separate consideration of the influence of game design patterns and gamification best practices for rehabilitation system design. This allows us to separate functional aspects of game design from motivational qualities of game interaction and can enhance the quality of design. A novel approach in our PACT work flow illustration is the use of Marczewski's gamification Hexad to help identify ways in which different people can be motivated to participate. PACT has been developed ahead of a new three year project which seeks to design and develop motivating game-based exercise systems for people affected by Multiple Sclerosis.

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Smart cane outdoor navigation system for visually impaired and blind persons

B Chaudary, P Pulli

Department of Information Processing Science, University of Oulu,

Pentti Kaiteran katu 1, 90570 Oulu, FINLAND

babarcha@paju.oulu.fi

www.tol.oulu.fi

ABSTRACT

This paper presents prototype of an outdoor navigation system designed to assist visually impaired (VI) and blind persons in outdoor navigation. It assists VI persons in moving independently on sidewalks in urban areas using an augmented guidance cane and informs them about points of interests (POI) through serialized braille encoded vibrational guidance messages. Augmented guidance cane, magnet points' trail, metallic trail, and pulsing magnet apparatus for transmission of serialized braille encoded guidance messages in the form of vibration are the features of the proposed navigation system. Magnet points' trail, metallic trail, and pulsing magnet apparatuses will be installed on the special sidewalks for the visually impaired persons in city centers. VI persons will be able to sense magnet points' trail or metallic trail through augmented guidance cane. It will assist them to walk independently being oriented on the sidewalks. Pulsing magnet apparatuses will be installed at the verge of the POIs on the sidewalks. VI persons will be able to sense the serialized braille vibrational messages through augmented guidance cane and become aware of the POI. Numbers of usability experiments are designed to evaluate the usability of the proposed system in qualitative interviews sessions. It is expected that the results of the qualitative interviews and the test sessions will provide valuable information to make this prototype a full-fledged system ready to be deployed.

1. INTRODUCTION

Navigating complex routes and finding objects of interest are challenging tasks for the VI persons and in today's world there is a lack of infrastructures to make it easier. One of the most problematic tasks for them is outdoor navigation. They cannot do it without assistance even if the place is small. This element is typically termed as Macro-Navigation or Orientation in the literature (Katz et al, 2012a). It includes multiple processes such as being oriented, selecting an appropriate path, maintaining the path, and detecting when the destination has been reached (Downs and Stea, 1977). These tasks are dedicated to processing the remote environment, beyond the immediate perceptible ones. In the case of visual impairment, main cues (e.g. landmarks and paths) for sensing the environment are degraded. This results in difficulties relating to correct orientation or heading, piloting (i.e. guidance from place to place using land marks) and retaining the path etc. (Katz et al, 2012b).

Despite over a decade of intensive research and development, the problem of delivering an effective navigation system to the blind and vision impaired remains largely unsolved (Kamiński and Bruniecki, 2012, Wise et al, 2012). Navigation support for VI people involves the use of textured paving blocks, guide dogs, GPS based navigation systems, and different sensors and wireless based systems among others (Hersh and Johnson, 2010). Macro-navigation systems are almost exclusively based on the use of Global Positioning System (GPS) with adaptations for VI users. Other technologies widely used for macro navigation are the Radio Frequency Identification (RFID) and using radio waves emitted from a wireless LAN access point (Domingo, 2012, Yelamarthi et al, 2010). Though these technologies and navigation assistances suffer from certain limitations for being an optimum solution for a navigation system for the VI persons. Compared to public spaces and transport facilities, no progress is being made in providing commercial facilities with textured paving blocks. Although guide dogs are effective on obstacle-free safe walkways, they cannot locate a person's destination (Katz et al, 2012b). As for GPS, the highest quality signal is reserved for military use, and the signal available for civilian use is intentionally degraded. The precision of civilian GPS is 10 meters (33 ft.) (Letham, 2011). This is insufficient accuracy for such systems. GPS also often suffers from serious errors caused by multipath propagation (Bauer, Marcus, and Gerd, 2012). RFID technology has reportedly many shortcomings including fluctuating signals accuracy, signals disruption, reader and/or tag collision, slow read rates. Wireless LAN access point method has encountered issues with fluctuating positional accuracy due to reflected signals from the wireless LAN, obstacles, or the surrounding environment (Kolodziej and Hjelm, 2010). Studies into guidance systems using tactile maps, which are effective in creating mental maps, are also underway. However, it takes time to understand tactile maps by touch, and therefore, they are difficult to use when on the move (Nakajima and Haruyama, 2012).

To address these kind of issues, our study aims to develop a usable system that enables VI persons, especially the blind/deaf blind walking independently in urban areas and finding points of interest (POI) like post office, shopping mall, bar or coffee shop etc. The proposed prototype is designed using magnet trails, metallic trails, pulsing magnet apparatus, and a serialized version of braille writing system. It helps VI persons in orienting and piloting their journey on the sidewalks and informs them about POIs in the surroundings through serialized braille encoded vibrational guidance messages.

This study is organized as follows. Sections II describes serialized braille code. Section III illustrates proposed prototype for the overall system design, hardware components of the system, and the serialized braille vibrational messages transformation method is described. Section IV describes qualitative interview session and usability tests. Section V concludes the paper with describing results and summary of the study.

2. SERIALIZED BRAILE CODE

Braille is a tactile writing system enabling blind and partially sighted people to read and write through touching braille characters (Braille, 1829). Braille is chosen as communication medium for the prototype to communicate with blind users. Though reading braille is difficult than writing braille. That's why it's difficult to use braille as a communication method in navigation systems for VI persons. For that reason, a serialized braille code compliant of the traditional braille is developed for this study

2.1 *Serialized braille transformation*

The numbering system that is assigned to braille cell dots is basic for the conversion of conventional braille into serialized braille. The braille code consists of three rows and two columns i.e. three by two matrix of cells. Position of each dot is assigned a specific number and combinations of those dots formulate different braille characters. A serialized braille code could be devised by positioning two columns serially rather than parallel and get numeral value for each braille character.

3. SYSTEM DESIGN

The system comprises of four components:

- *Augmented guidance cane*
- *Stationary magnet points Trail*
- *Metallic trail*
- *Pulsing magnet apparatus*

Stationary magnets points trail and metallic trail are two contending components. Either of these will be used as part of system after experimentation during user tests.

3.1 *Augmented Guidance Cane*

It is a regular white cane used by visually impaired persons fitted with a small magnetic reader at its bottom, Fig 1 C. The magnetic reader is a ring shaped N40 type powerful Neodymium magnet installed on tip of the cane.

3.2 *Stationary Magnet Points Trail*

Stationary magnet points trail will be made on the sidewalks for the blind and VI persons in city centre. It will comprise of powerful Neodymium N42 type disc magnets buried beneath trail on sidewalk, Fig1 A. A VI person walking on sidewalks can sense and follow these magnetic points to walk through her augmented guidance cane.

3.3 *Metallic Trail*

Metallic trail comprises of pure iron tabular pipe buried underneath the sidewalks, Fig1 B. The VI persons can sense and follow the metallic channel through their augmented guidance cane.

3.4 Pulsing Magnet Apparatus

Pulsing magnet apparatus generates and relays magnetized serialized braille vibrational guidance messages about POI, Fig 1 D. These are installed at the verge of POIs on sidewalk. When a VI person reaches at pulsing magnet apparatus, she can feel the serialized vibration emitted from it through her cane and becomes aware of POI. These serialized vibrations emit serialized encoded guidance message that VI can get by decoding it.

3.4.1 Architecture of Pulsing Magnet Apparatus: Architecture of pulsing magnet apparatus comprises of four components:

- *Micro Controller Unit (MCU).* MCU encodes a guidance message into serialized braille form and sends it to an electromagnetic coil in the form of serialized electric pulses.
- *Electromagnetic coil.* An electromagnetic coil developed in the lab is used to emit serialized braille vibrational message through pulsing electromagnetism, Fig 1 E. It replicates the serialized electric pulses sent from MCU in the form of pulsing electromagnetism. The polarity of electromagnetism is reversed with each pulse. The reversing polarity causes white cane magnetic reader to be pushed and pulled by electromagnetic coil with each pulse. This phenomena cause vibration effect
- *H-Bridge.* An H-Bridge is used in pulsing magnet apparatus to change polarity of the electrometric coil. An H-bridge is an electronic circuit that enables a voltage to be applied across a load in either direction (Williams, 2002).
- *Reed-Switch.* The reed switch is an electrical switch operated by an applied magnetic field. It is used to save power consumption. Reed turns on the pulsing magnet apparatus when it detects the magnetism of augmented cane carried by VI persons and turns it off when magnetism is absent.

4. QUALITATIVE INTERVIEWS SESSION

A semi structured interviews session is designed to collect complementary qualitative data from stack holders of the system. First session is a comprehensive study that investigates blind end users' white cane usage pattern, outdoor visits routine, role of alternative senses in navigation, acceptability of new assistance approaches, and post-test feedback about current prototype, appendix A. The interviews are guided by dramaturgical model (Myers and Newman, 2007).

4.1 Quality function deployment (QFD)

Quality Function Deployment is a method for satisfying customers by translating their demands into design targets and quality assurance points (Akao, 2004). It will be used to transform user demands into design quality.

5. USABILITY TESTING

Usability test sessions to test the usability of the system and remove problematic features from it are designed. These test sessions will be done involving real blind persons will be conducted in autumn 2014.

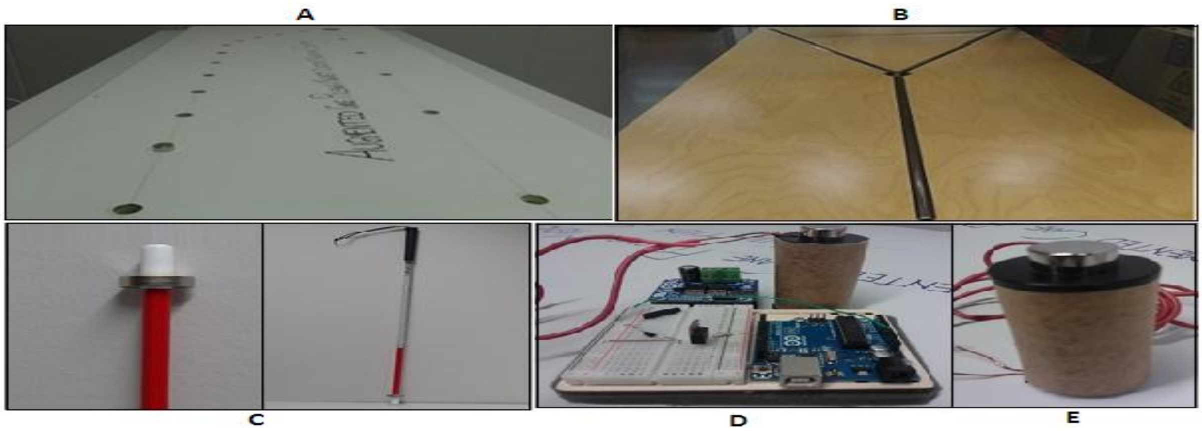

Figure 1. *(A) Magnet points trail test bed, (B) Metallic trail test bed, (C) Augmented guidance cane, (D) Pulsing magnet apparatus, (E) Electromagnet coil.*

6. CONCLUSIONS

In this paper, prototype of an outdoor navigation system to assist visually impaired blind persons in outdoor navigation is presented. Three learning phases of overall system for end users and usability tests to evaluate usability factors of the system in each of its three learning phases is been described. Result of usability testing could improve design of prototype based on feedback of end users. Quality function deployment (QFD) framework will be used to convert user demands into design quality. We expect that participants could complete their tasks with the help of navigation system. Task accomplishment could fulfill expected efficacy and effectiveness of system. Usability test will provide with actionable suggestion to increase usability of navigation system.

Acknowledgements: This paper has been written as part of ASTS Project funded by Academy of Finland and Japan Science technology Agency (JST). We want to thank Timo Jämsä, Maarit Kangas, Niina Keränen, Eeva Leinonen, and Pekka Räsänen for contribution, co-operation and fresh ideas.

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Video-based quantification of patient's compliance during post-stroke virtual reality rehabilitation

M Divjak, S Zelič, A Holobar

Faculty of Electrical Engineering and Computer Science, University of Maribor,
Smetanova ulica 17, 2000 Maribor, SLOVENIA

matjaz.divjak@um.si, *simon.zelic@um.si*, *ales.holobar@um.si*

www.feri.um.si

ABSTRACT

We present a video-based monitoring system for quantification of patient's attention to visual feedback during robot assisted gait rehabilitation. Patient's face and facial features are detected online and used to estimate the approximate gaze direction. This gaze information is then used to calculate various metrics of patient's attention. Results demonstrate that such unobtrusive video-based gaze tracking is feasible and that it can be used to support assessment of patient's compliance with the rehabilitation therapy.

1. INTRODUCTION

Stroke is the third most common cause of death in Western society, with ~4.7 million stroke survivors alive today. One of the hallmark residual impairments of stroke is post-stroke walking disability, which creates a stigma for patients, makes them more susceptible to injury and directly affects their quality of life. Early rehabilitation therapy is crucial for significant improvements (Kollen et al, 2006). In recent years, robotic systems are widely tested and employed to retrain stroke patients. By imposing gait-like movements at a comfortable speed, such robotic devices are thought to provide many of the afferent cues regarded as critical to retraining locomotion (Mehrholz et al, 2007).

However, a major problem with existing stroke therapies is patient non-compliance (Matarić et al, 2007). Many stroke patients abandon the therapy because the process is too long, repetitive, and/or does not provide immediate results (Teasell and Kalra, 2005). European project BETTER (Project, 2013) recently addressed a new approach to gait rehabilitation by employing non-invasive brain-neural computer interaction (BNCI) based assistive technologies based on EEG, EMG and IMU sensors. In this paper we extend the BNCI-based modalities with video-based attention monitoring system that allows automatic quantification and long-term monitoring of user attention. Such attention tracking does not require any sensors to be attached to the patient, making this method easy and fast to apply in stroke rehabilitation. Our main objective is to quantify patient's attention to visual feedback, i.e. the amount of time the patient's gaze is actively following the displayed visual feedback and to inspect the possible impact of visual feedback on motor planning, as well as its short- and mid-term benefits.

Several studies already examined the impact of visual feedback on stroke rehabilitation, but they mostly reported inconclusive results. They focused on quantification of results of rehabilitation enhanced with different kinds of visual feedback, but their experimental designs did not allow for a reliable quantification of the attention a person is paying to stimuli. To the best of our knowledge, only psycho-physiological measures of patient's attention to visual feedback have been reported in the literature (Bakker et al, 2007), while video-based assessment of attention has not been proposed in the field of rehabilitation.

Methods for real-time detection of face, facial features, eye movements and gaze direction from video have attracted a lot of research in the past decade (Hansen and Ji, 2010). Numerous algorithms for facial feature extraction have been proposed, mostly in the context of face detection and recognition (Bagherian and Rahmat, 2008). Currently, the most promising approaches rely on fusing multiple visual cues, such as combining local feature matching with intensity-based methods (Liao et al, 2010). Existing methods for quantification of user's attention to visual feedback have mostly been developed for Human-Computer Interaction applications and in order to help severely disabled people (Poole and Ball, 2005).

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2. METHODS

An overview of our approach is depicted in Fig. 1. The patient is fixed in a robotic gait trainer, which moves patient's legs according to predefined rehabilitation scenarios, adapted to patient's current walking abilities. In front of the patient is a large TV screen showing various visual feedbacks. A high speed video camera is mounted above the TV. The camera captures HD video of patient's face, while simultaneously EEG is recorded from 51 scalp sites and EMG is recorded from both legs (tibialis anterior).

The video streams are processed by our algorithms. First, frontal faces are detected and main facial features are extracted (corners of the eyes, pupil centers, mouth, tip of the nose). To suppress jitter from detection errors and body swings during walking, a Kalman filter is applied to the locations of extracted facial features. Next, an active appearance model (AAM – Matthews et al, 2007) of the face with 59 facial landmarks is used to more accurately represent the current facial pose/expression. The distances between extracted landmarks are used to calculate the head pose and gaze direction. Finally, different metrics of patient's attention /compliance are computed: percentage of time the patient is observing the visual feedback, spatial gaze distribution maps, responses to actions in the VR environment, etc.

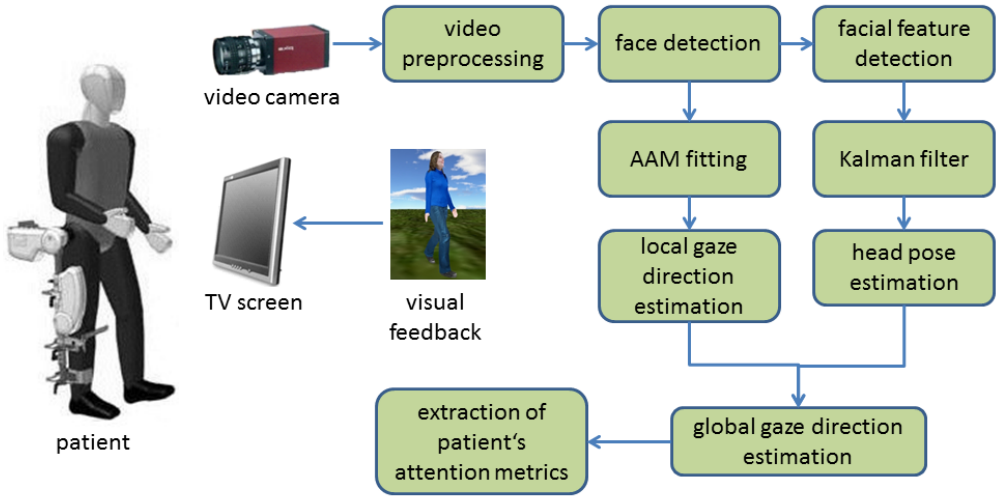

Figure 1. *Overview of the proposed approach for video-based estimation of patient's attention/compliance during robot-enhanced rehabilitation.*

We tested 5 different visual feedbacks (Fig. 2): calibration screen for initialization of our algorithms, 2D plots of current leg positions, 2D plots of muscle activations, and two realistic VR environments (walk in a park from 1st and 3rd person perspective). The VR environments were created in OpenGL 3.3 and consist of ground, sky dome and male/female avatars. The avatars were created in Mixamo Pro Character Creator Tool and animated with AutoDesk 3DS Max 2012. Both avatars have an underlying bone structure with all major joints modeled, allowing animation of almost all human movements. The actual avatar movement within the VR environment is controlled by kinematic data from the robotic trainer, so leg movements in VR world correspond with leg movements in real life.

The whole video processing system was designed for real-time operation, but current version of the software is a mix of C++ and Matlab routines and runs at ~1 frame per second. Therefore, all video processing is currently performed offline, but (near) real-time operation is possible with further optimization of the code.

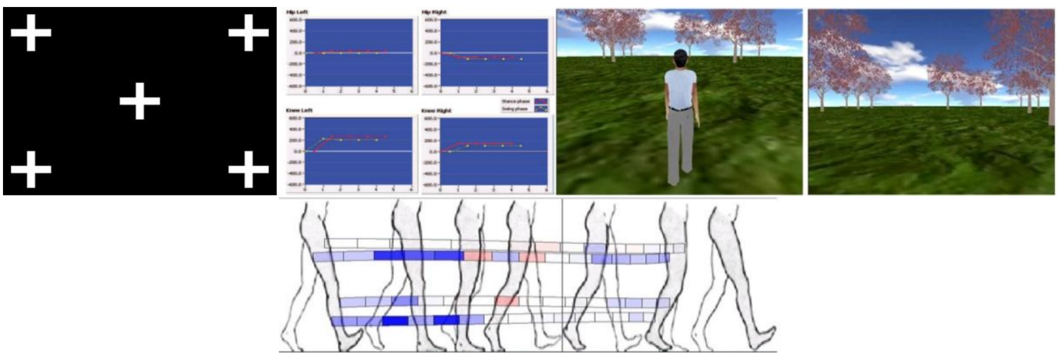

Figure 2. *Five different visual feedbacks that are shown to the patient during therapy.*

3. EXPERIMENTAL RESULTS

The proposed system was evaluated in an experiment that involved 4 stroke patients and consisted of 5 runs of robot assisted walking with different visual feedbacks. In all runs, the patients were instructed to walk actively, maintaining a constant speed, and applying minimum force on the robot. A 42" screen was placed in front of the patient, 1.4 m away from his face. Each run lasted 4 minutes. For all visual feedbacks the walking speed remained constant. During the experiments videos of the patient's face were recorded to disk and later processed offline.

On average, the face was detected in 93 % of video frames recorded (i.e. in practically all the frames with frontal faces whereas the profile faces were not detected). Eyes, mouth, nose, and pupils were accurately detected in more than 99% of detected faces (Table 1). Detection of facial features was skipped in video frames with no face detected. The average jitter of detected facial features was 1.0 ± 0.4 pixels. The AAM was successfully fitted to all frontal faces. The average jitter of AAM landmarks was estimated at 0.6 ± 0.4 pixels.

Table 1. *Facial feature detection performance, estimated on three test videos.*

	Video 1 (gaze targets)		Video 2 (gaze targets)		Video 3 (VR 3rd person)	
	frames	%	frames	%	frames	%
Whole video	9999	100 %	13391	100 %	10551	100 %
Face detection	9833	93.7 %	13193	98.5 %	10427	98.8 %
Detection of left eye	9805	99.7 %*	13174	99.9 %*	10419	99.9 %*
Detection of right eye	9769	99.3 %*	13179	99.9 %*	10408	99.8 %*
Detection of left pupil	9800	99.9 %#	13191	99.9 %#	10419	100 %#
Detection of right pupil	9769	100 %#	13187	100 %#	10408	100 %#
Detection of nose	9827	99.9 %*	13150	99.8 %*	10423	99.9 %*
Detection of mouth	9742	99.1 %*	13174	100 %*	10414	99.8 %*

* Values normalized by the number of face detections.

\# Values normalized by the number of eye detections.

Videos recorded during sessions with the screen displaying calibration targets were inspected by an expert and 9 approximate gaze direction (top-left, top-centre, top-right, bottom-left, bottom-centre, bottom right, left-centre, right-centre and centre of the screen) were manually annotated. The time periods corresponding to eye movements or eye blinks were ignored and were not annotated. Gaze direction was then calculated automatically by our algorithm and compared to manually annotated gaze locations. The gaze directions were identified with average accuracy of 94% ± 6%. Most errors originated from distinguishing between top-left vs. bottom-left and top-right vs. bottom-right gaze directions.

Fig. 3 shows an example of patient's detected level of attention to visual feedback, estimated as percentage of time in 1 second intervals with gaze fixed to the TV screen; all gazes outside the screen were classified as non-attention. Fig. 4 presents an example of the estimated spatiotemporal gaze distribution metric. This metric shows relative frequency of identified gaze locations over 4 minutes long gait rehabilitation. Brighter spots in the gaze distribution plots indicate areas with more frequent attention. Such maps support identification of gaze targets (i.e. gaze hot-spots) and assessment of spatiotemporal correlation between patient's attention to visual feedback and other BNCI-based performance indices of gait rehabilitation.

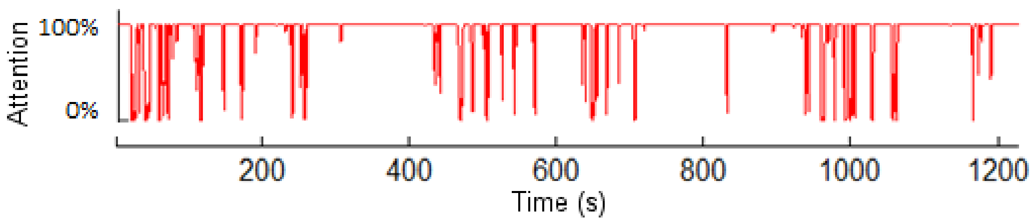

Figure 3. *An example of estimated level of patient's attention to visual feedback.*

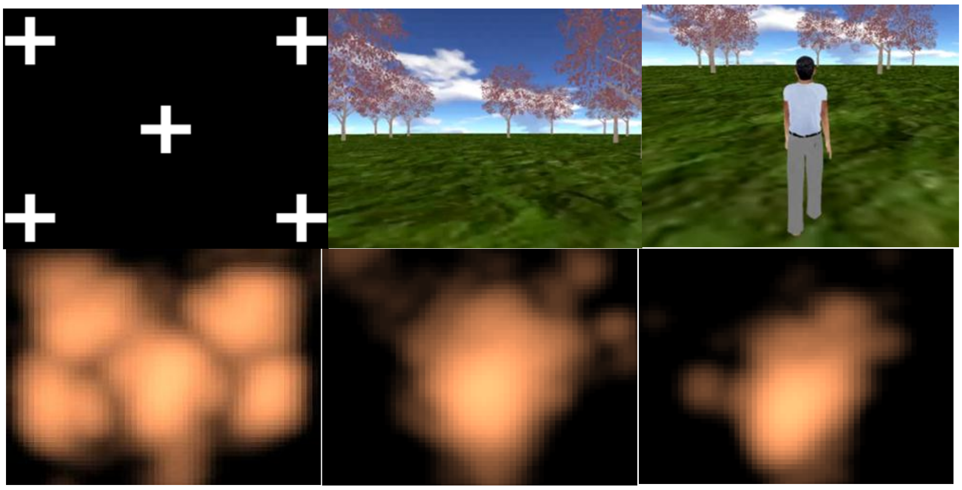

Figure 4. *Example of spatial gaze distribution plots (bottom row) for three different visual feedbacks (top row) shown to a patient during 4 minutes long gait rehabilitation.*

4. CONCLUSIONS

We developed and validated a video-based system for robust tracking of patient's face pose and gaze direction during robot-assisted lower limb rehabilitation therapy. The results (Fig. 3 and Fig. 4) show that such system can be used to unobtrusively analyze patient's attention to displayed visual feedback and to provide means for long-term quantification of visual feedback effects on the rehabilitation progress. It can also serve as an additional feature for other BNCI performance indices, such as similarity of motor modules, kinetic and kinematic profiles and brain patterns. For example, preliminary results show significant correlation between attention to muscle activation plots and improvements in muscle activations during walking.

Acknowledgements: This work was supported by the Commission of the European Union within Framework 7, grant agreement FP7-2009-7.2–247935 - "BETTER – Brain-Neural Computer Interaction for Evaluation and Testing of Physical Therapies in Stroke Rehabilitation of Gait Disorders". The authors would like to thank the personnel of Fondazione Santa Lucia, Rome, Italy, for organizing and performing the experimental recordings.

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Virtual spatial navigation tests based on animal research – spatial cognition deficit in first episodes of schizophrenia

I Fajnerová[1,2], K Vlček[2], C Brom[3], K Dvorská[1] , D Levčík[2], L Konrádová[1], P Mikoláš[1], M Ungrmanová[1], M Bída[3], K Blahna[2], F Španiel[1], A Stuchlík[2], J Horáček[1], M Rodriguez[1]

[1]Prague Psychiatric Center,
Ústavní 91, Prague 8, CZECH REPUBLIC

[2]Department of Neurophysiology of Memory, Institute of Physiology, Academy of Sciences of the Czech Republic, Vídeňská 1024, Prague 4, CZECH REPUBLIC

[3]Dept. of Software and Computer Science Education, Faculty of Mathematics and Physics, Charles University, Malostranské nám. 25, Prague 1, CZECH REPUBLIC

fajnerova@pcp.lf3.cuni.cz, kamil.vlcek@fgu.cas.cz

[1]*www.pcp.lf3.cuni.cz/pcpeng/,* [2]*www.fgu.cas.cz/332,* [3]*ksvi.mff.cuni.cz*

ABSTRACT

The impairment of cognitive functions represents a characteristic manifestation in schizophrenia. Animal models of schizophrenia demonstrated behavioural changes in several spatial tasks. In order to assess spatial abilities in schizophrenia using methods applicable in comparative research, we designed two virtual tasks inspired by animal research: the Morris water maze and the Carousel maze. The tested subject is required to navigate toward several hidden goal positions placed on the floor of an enclosed stable arena or a rotating arena. Data obtained in a group of schizophrenia patients show cognitive impairment in both newly-developed virtual tasks comparing to matched healthy volunteers.

1. INTRODUCTION

The cognitive deficit is considered to be a characteristic and permanent manifestation accompanying schizophrenia and related psychotic disorders, affecting several cognitive domains including visual learning and memory (Green et al, 2004). Spatial tasks have the potential to assess similar cognitive performance in humans and animals. Impairment of visuo-spatial abilities has been already demonstrated in animal models of schizophrenia (e.g. Lobellova et al, 2013) and also in schizophrenia patients using various virtual tasks developed on the basis of the original paradigm for animals (e.g. Hanlon et al, 2006; Spieker et al, 2012).

In order to assess complex spatial abilities in schizophrenia and compare our results with the data obtained in animal models, we designed two virtual reality tasks adopted from the animal research, the Morris water maze and the Carousel maze paradigm. Experiments have been conducted in virtual reality (VR) that allowed us to build large-space and/or moving environment.

Due to the potential of VR to easily modify the environmental stimuli, the newly-developed tests could be applied in longitudinal clinical studies, such as the non-pharmacological intervention provided by the Prague Psychiatric Center. This computer-based and individually oriented cognitive remediation for psychotic patients combines several cognitive rehabilitation methods for 8 weeks (Rodriguez, 2013) and could later proceed in a form of online training (neurokog.pcp.lf3.cuni.cz; in development). Retest variants of the presented tests could be applied to test the outcome of therapy by monitoring complex spatial behavior.

2. METHODS

2.1 Participants

A study group of 30 (17 males and 13 females, age 18-35) first-episode schizophrenia patients (SZ, diagnosed as acute psychotic episode or schizophrenia according to DSM-IV) and a control group of healthy volunteers (HC) were recruited and matched for age, sex, education level and gaming experience.

2.2 Apparatus and software

The game engine Unreal Tournament (UT2004; Epic Games) was used to visualize the virtual scene to the respondents presented in a first-person view on a 24" LCD monitor. The custom-made java software toolkit called “SpaNav” was connected to the game engine to control the experiment and collect online data. Subjects controlled their movements in virtual environment using only one joystick of the gamepad device.

2.3 Design and Procedure

Prior to the experiment all participants underwent a short pre-training of movement control in complex virtual maze. Consecutively all performed experiment in two virtual tasks, which required the subject to navigate towards one of the 4 hidden goal positions placed on the floor of an arena, stable or rotating. Each single trial started with pointing towards the goal and was followed by navigation towards the goal using three visible orientation cues.

2.3.1 Stable arena. The virtual task with the hidden goal paradigm was inspired by the Morris water maze (MWM; Morris, 1984) and was performed in a large-scale enclosed virtual arena (see Fig. 1B). This virtual Four Goals Navigation (vFGN, Fajnerova et al, 2014) task requires the participant to find and remember the hidden goal position on the floor of an enclosed virtual tent using three visible orientation cues. Four separate phases of the vFGN task represent the analogies of the MWM protocol variants: *1) Training* - reference memory protocol with stable goal position, *2) Acquisition* - reversal protocol with changing goal position, *3) Recall* - delayed matching-to-place protocol, *4) Probe* - trials with removed goal position (without feedback).

2.3.2 Rotating arena. The second virtual test was inspired by the Carousel maze - Active allothetic place avoidance (AAPA) task - performed on a rotating arena (Cimadevilla, 2000). However, the original avoidance task was modified to a preference version of the task, as a virtual arena called the Active Allocentric Place Preference task (AAPP, Vlček et al, unpublished). The same hidden goal principle as in the previous task was used to test spatial abilities in subjects standing on a rotating arena. The hidden goal positions are either connected: 1) to the ARENA frame and rotate together with the tested individual or 2) to the ROOM frame moving with respect to the subject/arena (see Fig. 1D). Time limit for each trial was 20 s. The task was divided to four separate phases: *1) Training* - searching for two goals, one in the arena frame and one in the room frame; *2) Arena frame* - navigation towards two stable goals in arena frame; *3) Room frame* - navigation towards two moving goals in room frame; *4) Frame switching* - alternated search between 4 goals placed either in arena frame or in room frame.

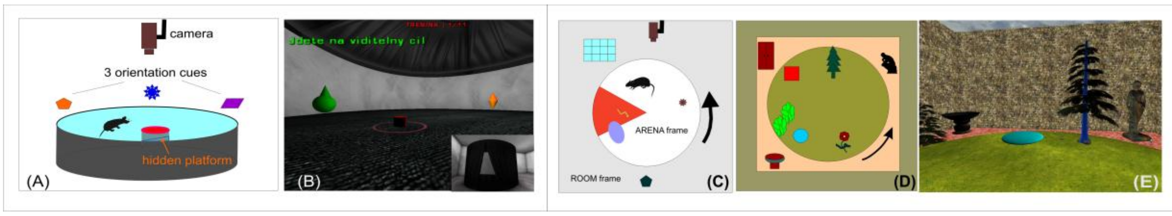

Figure 1. *MWM paradigm (adjusted from Fajnerova et al, 2014): (A) model of the original MWM apparatus for rats; (B) Virtual version, the vFGN task in an enclosed dry arena. (C) The AAPA task. (D-E) Virtual version - the AAPP task. (D) Schematic view of the Training conditions in two possible reference frames - Room frame (square shape) and Arena frame (circular shape).(E) Rotating arena from the first-person view.*

2.3.3 Clinical assessment. To confirm the cognitive deficit in our study subjects, all participants (SZ and HC) completed a battery of standard cognitive tests (Trial making test; Spatial Span (WMS-III); Rey-O/Taylor Complex Figure; Block Test (WAIS-III); Perceptual vigilance task, Money-road map test, Key-search test). In addition, all patients were evaluated using the PANSS and GAF psychiatric scales to address the presence of clinical symptoms.

2.4 Measured parameters and data analysis

The spatial performance measured in the *Stable arena* was in all except probe trials evaluated using two parameters, the *pointing error* (absolute angular difference between the pointed and linear direction towards the goal position) and the *path efficiency* (range 0 to 1, calculated as a ratio between the minimal path length and the real distance travelled by the subject). In probe trials the *goal quadrant preference* (proportion of the trial time spent in the correct arena quadrant) was evaluated. The performance in the *Rotating arena* was measured using the previously described *pointing error* parameter. The second applied *trial time* parameter represents the time needed to enter the goal position. Only selected parameters are presented in this paper. To analyze the data a custom-made PHP program called drf2track was used to produce primary data tables and trajectory pictures; further statistical analysis was performed in Statistica 11. The group differences were calculated using the repeated measures ANOVA and overall level of significance was set to 0.05.

3. RESULTS

The results of both virtual tests confirmed the deficit of cognitive abilities observed earlier using the battery of standard tests (not presented) in the group of first episode schizophrenia patients.

3.1 Stable arena

All phases of the vFGN task show decline in spatial abilities of schizophrenia patients in comparison to healthy volunteers (published in full extend in Fajnerova et al, 2014). The first Training phase demonstrates learning difficulties presented in lower pointing (Fig. 2A) and navigation accuracy ($p < 0.01$) in schizophrenia patients. The subsequent Acquisition phase with changing goal position as a measure of mental flexibility, showed only mild group differences in pointing ($p < 0.01$) but not in navigation accuracy (Fig. 2B – gray area), probably due to the skill learning effect (as all three goal positions were spatially identical). The recall of the three previously learned goal position sequence (ABC) in the later Recall phase showed deficit of spatial working/long-term memory demonstrated in significantly decreased navigation performance ($p < 0.001$) more expressed in the first repetition round (Fig. 2C). The last Probe phase without feedback about the correct position, showed significantly disturbed spatial bias in schizophrenia patients ($p < 0.001$), demonstrated in lower proportion of time spent in the correct arena quadrant (Fig. 2C).

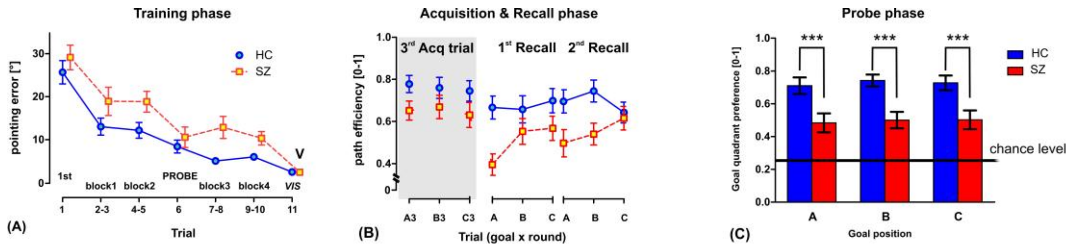

Figure 2. *Performance of both groups in the vFGN task (modified according to Fajnerova et al.,2014). (A) The Training session performance expressed using the pointing error parameter. (B) The path efficiency in Acquisition phase (last trial for each goal position) and in all Recall trials. (C) The time proportion spent in the correct arena quadrant in the last Probe phase.*

3.2 Rotating arena

Similarly, all phases of the virtual AAPP task show decline of spatial performance in schizophrenia. The first Training phase showed impaired learning abilities on the rotating arena ($p < 0.01$, Fig. 3A). The second phase performed in the 'stable' Arena frame showed only mild decrease in measured parameters ($p < 0.01$), less expressed in the second half (Fig. 3B). However, the third phase with navigation towards the moving goals connected to the Room frame (Fig. 3C) showed strongly profound decline of spatial abilities in schizophrenia ($p < 0.001$). The last phase created to assess the cognitive flexibility and coordination, as it required repeated switching between the two reference frames (switching between two mental maps, two sets of orientation cues for arena and room), shows substantial deficit in schizophrenia patients ($p < 0.001$, Fig. 3D).

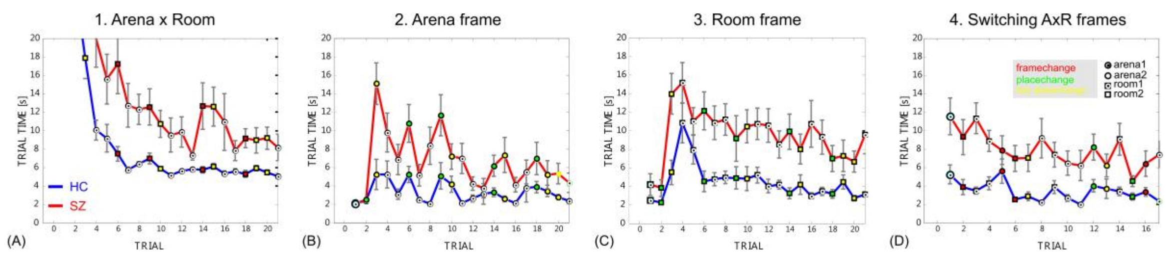

Figure 3. *(A-D) Performance of both groups in four phases of the AAPP task expressed using the trial time parameter. (A) The Training phase with simple frame switching (arena x room). (B) The Arena frame performance. (C) The Room frame performance. (D) Alternation between all 4 previously acquired goal positions, placed in one of the two reference frames.*

4. CONCLUSIONS

Presented results show significant deficit of visuo-spatial functions in first episode schizophrenia patients, which are demonstrated in both tested paradigms (hidden goal search on stable/ rotating arena) and in all four phases of the two virtual tasks. This finding supports our results obtained using the battery of standard cognitive tests (not reported here) and also results of other studies (e.g. Hanlon et al, 2006; Kern et al, 2011), showing the necessity for remediation of spatial learning and memory after the first psychotic episode.

Despite the fact that both methods used the same hidden goal paradigm and the same amount of orientation cues (3 objects), the rotating arena shows more pronounced decline of the spatial performance in schizophrenia than the stable one. This is not surprising, as due to the arena rotation the task demands attention shifts and navigation in two frames of reference, in contrast to the stable arena.

Considering the fact that our results support the visuo-spatial deficit observed in animal model of schizophrenia (Lobellova et al, 2013), both tasks could be used as tools for future comparative research, in order to identify cognitive changes in neuropsychiatric disorders. In addition, we do believe that both virtual tasks could be useful in measurement of cognitive enhancement as an outcome of pharmacological or non-pharmacological treatment in neuropsychiatric disorders, as they address complex cognitive functions.

Importantly, individual phases of both presented tests demonstrated variable extent of sensitivity towards the cognitive deficit in schizophrenia, supporting our assumption that particular parts of each test examine distinct visuo-spatial functions (e.g. learning, working memory, flexibility etc.). The first test with Stable arena showed that the performance in recall and probe phase was more impaired than during the acquisition process. Similarly in the experiment on Rotating arena the navigation towards moving goals was more affected than the search for stable goal positions. These findings indicate that some parts of these virtual tasks could form suitable tools for future virtual remediation of impaired visuo-spatial abilities in schizophrenia.

The future analysis will be aimed on clarifying the relationship between the two newly-developed virtual tasks and the standardized test battery used in this study. In addition, we currently perform repeated assessment 1 year after the first hospitalization to test the persistence of the cognitive deficit, either after the full remission of symptoms or due to potential relapse of the illness. This measurement also addresses possible sensitivity of the developed methods toward the future course of illness in individual patients.

Acknowledgements: We thank ESO team members (study of first episodes of schizophrenia) for their assistance in the collection of clinical data. The study was supported mainly by IGA MH CR grant No. NT13386, and partially by projects No. NT14291 and NT13843; and by the institutional support (RVO: 67985823) and MH CZ - DRO (PCP, 00023752).

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Exploring haptic feedback for robot to human communication

A Ghosh[1], J Penders[1], P Jones[2], H Reed[3], A Sorranzo[4]

[1]Materials and Engineering Research Institute, [2]The Department of Humanities,
[3]Art and Design Research Group, [4]The Department of Psychology, Sociology and Politics,
Sheffield Hallam University, Sheffield, UNITED KINGDOM

ayan.ghosh@student.shu.ac.uk, {*j.penders , p.e.jones, h.reed, a.soranzo*}*@shu.ac.uk*

www.shu.ac.uk

ABSTRACT

Search and rescue operations are often undertaken in low-visibility smoky environments in which rescue teams must rely on haptic feedback for navigation and exploration. The overall aim of our research is to enable a human being to explore such environments using a robot. In this paper we focus on creating feedback from a robot to a human. We describe our first designs and trials with vibration motors. The focus is on determining the potential use of vibration motors for message transfer and our trials reflect whether different messages can be discriminated. We describe the testing procedure and the results of our first tests. Based on these results, we conclude that close spatial arrangement of the motors blurs individual signals.

1. INTRODUCTION

Search and rescue operations in fire incidents, are undertaken only when the ground is relatively passable (Penders et al, 2011); the major problem however is that the environment is smoke-filled and noisy. Lack of visual and auditory feedback make rescue teams rely on haptic feedback for navigation and exploration. Navigation concerns finding the way, while exploration involves exploring the environment and finding possible victims. Robots with a range of sensors on board might be helpful for such conditions. In addition, there are also everyday situations where vision and audibility are low, for instance, a visually impaired person trying to walk along a street.

An early work on robotic navigation assistance to the visual impaired is described in Tachi et al. (1983). They developed a guide-dog robot for the visually impaired, which guides the person. The robot tracks the handler using active sonar, and the handler wears a stereo headset, which provides coded aural feedback to notify whether the handler is straying from the path. There are no means to communicate with the robot, and the handler must learn the new aural-feedback code: the robot serves as a mobile beacon that communicates with the headset. More recently, Allan Melvin et al, (2009) developed a robot guide to replace a guide dog. We described a robotic guide in (Ghosh et al, 2014), the emphasis is on how well a person follows the robot; however the human does not have any control over the robot and thus cannot explore.

There is quite a difference between guidance and exploration. Guidance is limited to the robot leading the person or handler. This setting presupposes that the robot does the way-finding and the person just follows. Exploration concerns investigating the direct but yet unknown environment. As there is no-visibility, exploration has to rely on active haptic sensing. A widely used device for haptic exploration is a white cane as intended for the visually impaired. Inspired by this, Ulrich and Borenstein (2001) developed the GuideCane. It is a cane like device running on unpowered wheels, it uses Ultra Sound to detect obstacles. The handler has to push the GuideCane - it has no powered wheels- however it has a steering mechanism that can be operated by the handler or operate autonomously. In autonomous mode, when detecting an obstacle the wheels are steering away to avoid the obstacle. Obviously the feedback to the human remains implicit: the handle is the medium.

Our project aim is to build a robotic device for exploration purposes. We previously reported on our initial haptic mode experiments in which a person uses a simple passive device (a metal disk fixed with a rigid handle, as shown in Figure 1) to explore the immediate environment (Jones et al, 2013). The feedback from the disk to the handler remains implicit: it is restricted to what the handler feels when holding the stick. Experiments demonstrated the extreme sensitivity and trainability of the haptic channel and the speed with which users develop and refine their haptic proficiencies, permitting reliable and accurate discrimination between objects of different weights. The disc with rigid handle provided implicit feedback to the handler while the handler was operating it. The final aim is to use a powered robotic device. However, a major issue with a powered robotic device is that there is no room for active haptic sensing by the human and the feedback to the handler has to be made explicit. In this paper we focus on creating feedback from a powered robot to the handler. We describe our first designs and trials with vibrating motors. At this stage the focus is on determining the potential of a set of vibration motors for message transfer; the trials investigate whether different messages can be discriminated.

Figure 1. *Metal disc fixed with a fixed handle.*

2. FEEDBACK DEVICE

Our design incorporates a robot with an impedance filter, which is connected with a handle to the handler. Figure 2 shows the impedance filter - a skirt-like structure - which sits on top of the robot (Janani et al, 2013). The figure also shows the handle, the physical interface between robot and the handler. Our previous work (Ghosh et al, 2014) has reflected on various aspects of the handle design. While encountering an obstacle, the skirt is displaced. The displacement is measured (using Cable Reel Transducers); these measurements need to be transformed into some sort of a haptic input to the handler. Defining and designing the input signal for the human handler is our current objective.

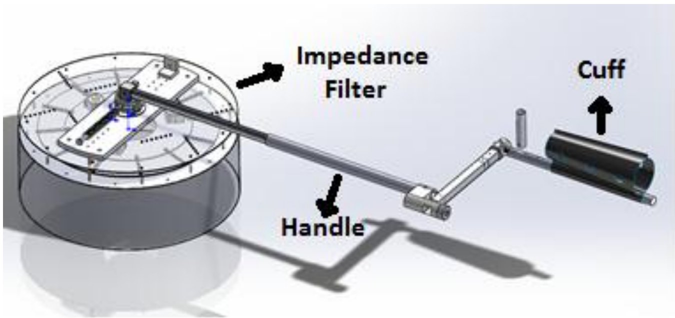

Figure 2. *The handle (with feedback cuff) and the impedance filter*.

We apply six vibrating motors, which are fixed on a wearable cuff (as shown in Figure 4) attached to the crutch-like part of the handle (as shown in Figure 2) . The motors vibrate for short periods (3-5 seconds) on the lower arm of the handler. The motors are individually controlled; however, all motors operate at the same frequency and intensity. They are connected through a microcontroller and operated using a software interface developed in Labview.

3. TESTING PROTOCOL

Figure 3 shows a person wearing the cuff on the lower arm. Our first question is whether subjects are able to distinguish which individual motors are activated; in addition our aim is to study whether different combinations of concurrent vibrating motors are recognisable. After one or more vibration motors were turned on for 3-5 seconds, the subjects were asked to report on the positions of the motors, by pointing out the options shown in the picture (Figure 3 right). To make it easier to understand, we named the positions as following: motors close to the wrist, Under Arm Bottom (UB) and Over Arm Bottom (OB), in the Middle as Under Arm middle (UM) and Over Arm Middle (OM) and close to the Elbow as Under Arm Top (UT) and Over Arm Top (OT), refer to Figure 5. Every subject was given noise cancelling ear protectors to neutralise all possible auditory cues.

Six subjects, aging between 22 and 55 without any medical condition, took part in our experimental study. Each subject was asked to undergo four sessions with twelve trials in each session. Before the commencement of the trials, the subjects were briefed about the experiment and went through a pre-trial in order to make them accustomed with testing environment and the apparatus. In the first trial set any of the six vibration motors is activated, but only one at the time. In the second trial set two motors are activated concurrently but in varying patterns and in the third set three motors are activated in varying patterns. The final session consists of a mix of single, double or triple motor activations in a random order.

Figure 3. *(Left) The cuff on trial and the trial's feedback display. (Right) The picture placed in front of the subjects for pointing out the positions.*

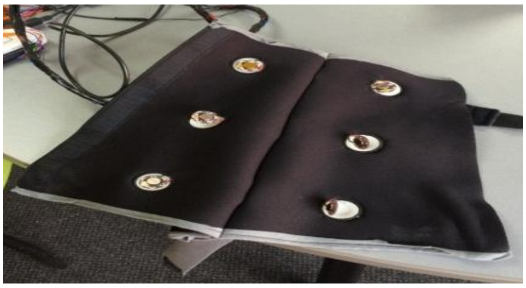

Figure 4. *Feedback cuff.*

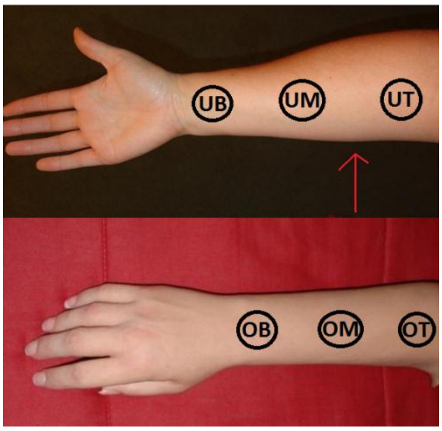

Figure 5. *Position of the vibration Motors.*

4. RESULTS

Figure 6 shows the errors subjects made in identifying the specific motors for the first three trial sets. The figures show motor positions on the horizontal axis; the vertical axis shows the proportion of errors (0-1) made when the respective motors were activated. Figure 6 left, shows the error proportions with single vibrating motors, the figure in the middle shows error proportions with two vibrating motors and the figure on the right shows error proportions with three vibrating motors. We notice that there is an increase in the number of errors as the number of vibrating motors increases. It is evident that the subjects were most accurate in determining the positions of vibrations when only a single vibration motor was turned on.

Average proportions of errors for the 3 different trial sets were as follows:

- Set 1 (single vibrating motor; 6 trials): 0.125 (0-1)
- Set 2 (2 motors vibrating concurrently; 12 trials): 0.22 (0-1)
- Set 3: (3 motors vibrating concurrently; 12 trials): 0.40 (0-1)

These results indicate the increasing difficulty in accurate identification of vibrating motor(s) over the three sets.

For the first set of trials involving single vibration motors, error rates were low. A repeated one-way ANOVA measure on the arc sin transformation of the proportion of errors showed no significant difference across the six motor positions ($F(5,5) = .87$; $p. = 0.51$).

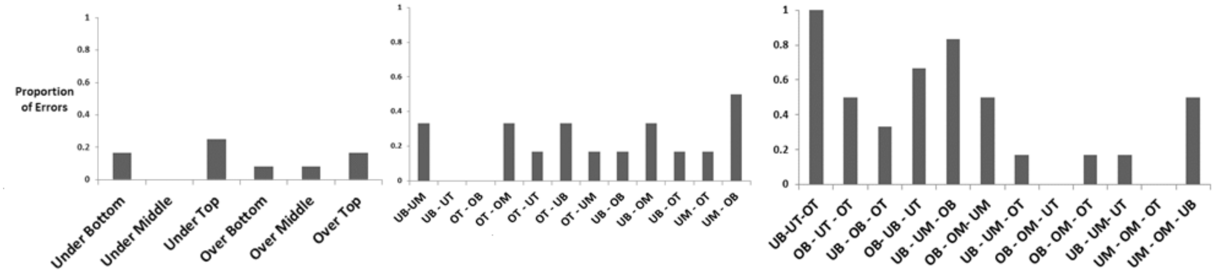

Figure 6. *Proportion of errors, single (left); double(middle);triple(right).*

For the second set of trials, error rates were higher than for the first set but still rather low. A repeated one-way ANOVA measure on the arc sin transformation showed no significant difference in proportion of errors across the twelve trial conditions ($F(5,11)= .73$; $p. = 0.7$) involving pairs of concurrently vibrating motors.

In the third set of trials in which three motors were activated concurrently, the error rates are high. Furthermore, the one-way ANOVA ($F(5,11)= 3.89$; $p. < 0.01$) showed a significant difference in proportion of errors across the twelve trials. It would appear, then, that the task becomes much more challenging with three vibration motors switched on and also that some of the triple-combinations are more readily identifiable than others, although the precise reasons for this extra level of difficulty are not clear. Anecdotal evidence suggests that identification difficulties may be associated with distribution or proximity of the motors on the arm but we were unable to establish this from our present data.

5. CONCLUSIONS and FUTURE WORK

The findings of the experimental trials raise a number of issues that need to be taken into account for future re-design of the cuff and the message-sending configurations of vibrating motors. The trial data show that subjects were easily able to distinguish when individual vibration motors were activated but that the difficulty of the task increased when motors were combined. Combinations of three motors, in particular, were especially difficult to identify accurately.

For these reasons, present work is focussed on the use of a cuff with only four vibration motors (two on each side) which will be used either singly or in pairs to transmit messages. Future experiments will also investigate whether specific signatures in vibration frequency and intensity for each motor may improve recognition. A next step is to define and design feedback signals (a sort of haptic alphabet) that correspond with displacements of the impedance filter.

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Kinecting the moves: the kinematic potential of rehabilitation-specific gaming to inform treatment for hemiplegia

S M N Glegg[1], C T Hung[2], B A Valdés[2], B D G Kim[2], H F M Van der Loos[2]

[1]Therapy Department, Sunny Hill Health Centre for Children,
3644 Slocan Street, Vancouver, B.C., CANADA

[2]Department of Mechanical Engineering, University of British Columbia,
6250 Applied Science Lane, Vancouver, B.C. V6T 1Z4 CANADA

sglegg@cw.bc.ca, tina.ct.hung@alumni.ubc.ca, bulmaro.valdes@alumni.ubc.ca, brandonkim.bk@alumni.ubc.ca, vdl@mech.ubc.ca

http://caris.mech.ubc.ca/feathers/

ABSTRACT

Two therapy applications for hemiplegic arm rehabilitation were developed and tested, along with a motion tracking application that used two interfaces (PlayStation® Move and Microsoft® Kinect™) for videogame play through a social media application developed on Facebook©. To promote affected arm use, users are required to employ bimanual symmetrical hand motions. Preliminary kinematic data analysis of two subjects obtained during user testing is presented. Clinically relevant information, such as range of motion, trunk compensation, and total distance of hand movement was extracted from kinematic data. Results showed the system is capable of accommodating users with large variation in arm function.

1. INTRODUCTION

The use of commercial gaming systems is gaining momentum in the field of rehabilitation (Galvin and Levac, 2011). These systems have been applied to target physical rehabilitation goals including upper extremity function (Luna-Oliva et al, 2013). Challenges exist, however, in the application of these systems to meet the therapeutic needs and physical capacity of different patient populations. Therapeutic gaming may be one treatment tool selected by therapists for individuals with hemiplegia as a means of providing opportunities for repetitive motor practice that targets specific movement patterns and encourages the use of the impaired limb (Orihuela-Espina et al, 2013). Accordingly, the development of novel game applications and user interfaces for these commercial systems is expanding the potential for the technology to be integrated in this way.

The purposes of this paper are to describe the development of two commercial interfaces (PlayStation Move and Microsoft Kinect) that were adapted to promote bilateral arm use during social media-based game play, and to share preliminary kinematic data of two subjects with hemiplegia using the systems. The analysis of kinematic data offered by the systems allows for the extraction of clinically relevant information that can be shared with patients' therapists for further interpretation. Both PlayStation and Kinect systems are capable of determining the total distance moved in a session, range of motion (ROM) of the user, and hand offsets for different directional movements. Moreover, the Kinect system is capable of determining excessive trunk movements.

2. METHOD

2.1 System Description

In order to use the two motion capture interfaces, a computer application (FEATHERS Motion) was developed for the upper limb rehabilitation of hemiparetic users. Another application, FEATHERS Play on Facebook, enabled users to connect with their therapists and other participants, to receive recommendations about games, and to review their game scores. An alternate version of the application was developed for therapists to monitor users' game scores and facilitate communication with their patients. Both applications were refined based on the results of previous usability testing conducted with rehabilitation professionals (see Valdés et al., 2014 for more details).

The FEATHERS Motion application relies on the use of bimanual motions in the frontal plane to control the mouse cursor on a Windows® 7 personal computer. Two motion modes (Visual Symmetry and Point Mirror Symmetry) are available for mapping the hand with the least movement into cursor motion. In the Visual Symmetry mode, users are required to move both hands at the same time in the same direction. In the Point Mirror Symmetry Mode, users must move both hands around the circumference of a circle, similar to steering a wheel.

2.2 Participants

Participants were two male adolescents recruited through therapists at a local rehabilitation centre. Subject 1 (19 years old) was right-hand dominant and presented with left hemiparesis with increased finger flexor tone post-traumatic brain injury and brachial plexus injury two years prior. Some decreases in both active and passive ROM for shoulder flexion, extension and external rotation persist. He was also observed to compensate with his flexors during shoulder abductions. Subject 2 (13 years old) was left-hand dominant prior to incurring a stroke 14 months ago. He presented with right hemiparesis, with weakness of the external rotators of the shoulder, no active supination of the forearm and decreased wrist flexor and extensor strength. A healthy right-handed male control (28 years old) participated as a comparison.

2.3 Procedure

Each user test session included a moderator, note taker, caregiver/guardian and therapist. All sessions were audio and video recorded. University of British Columbia Ethics Board approval was obtained, along with informed consent from participants and a parent/guardian. Each user participated in a 90-minute session during which a set of tasks was completed to evaluate ease of use of the system. Users were introduced to the FEATHERS applications and the interfaces, and played “Lucky Pirate” (OUAT Entertainment) in both motion modes after receiving instructions on the movement and task requirements. Kinematic data was recorded for both interfaces, i.e., the 3D position of the PlayStation Move controllers and of all upper limb joints using Microsoft Kinect.

3. RESULTS & DISCUSSIONS

3.1 Performance Data for One Session

Joint position data were analyzed for 2.5-3 minutes per subject using six joints (wrists, shoulders, shoulder centre, and hip centre) during the Visual Symmetry play mode. Recommended filter values provided by Kinect for Windows SDK were applied to minimize jittering and to stabilize joint positions over time.

3.1.1 Total Distance Travelled in 2D. The total distance travelled by the wrists (Table 1) was calculated by subtracting the wrists’ horizontal (x-axis) and vertical (y-axis) positions from consecutive camera frames and summing the absolute values of the differences through the whole duration of the interaction. Because most of the wrists’ movements occurred in the frontal plane, only the horizontal and vertical positions were used for this calculation. In the next study phase where users are required to perform movements with larger variation in depth (z-axis), 3D data of the wrists will be used.

Subject 2, who had the greatest level of impairment, appeared to cover more distance than the other two subjects. Video and kinematic data analyses suggest that this might be related to his frequent need to rest his hands in his lap between movements. This effect can be observed in the large values for both vertical distances. Subject 2 was observed to employ compensatory movements of the trunk to accommodate for his limited upper limb motor control. Overall, the values for Subject 1 were closer to the healthy control’s results. This finding may relate to the shorter and more direct trajectories between targets compared to those of Subject 2. This observation may be explained by Subject 1’s greater motor ability and the fact that he kept his arms at chest level for most of the interaction.

Table 1. *Total Distance Travelled (* denotes hemiparetic side)*

	Horizontal (m)		**Vertical (m)**	
	Left Hand	**Right Hand**	**Left Hand**	**Right Hand**
Control	4.94	4.11	6.99	7.35
Subject 1	7.04*	6.07	8.22*	6.69
Subject 2	8.32	9.11*	13.85	7.64*

Therapists may find information about the total distance travelled useful, in conjunction with the straightness of the hands’ trajectories, in order to assess if the users’ movements are progressing towards healthy movement patterns. Distance travelled may have potential as an indicator of the recovery progress of participants.

3.1.2 Range of motion. Table 2 shows the ROM of each hand, computed based on the wrist movements of each subject (Figures 1-3). All figures were centred with respect to the median values of the hip centre. In the vertical direction for both hemiparetic subjects, and in the horizontal direction for Subject 1, larger ROM of the non-paretic versus the paretic arm was recorded. These findings are consistent with clinical presentation during functional tasks. Dissimilar findings for Subject 2 in the horizontal plane may be explained clinically by his limited control of the paretic side and his tendency to use compensatory trunk movements during play. The magnitudes of difference should be interpreted with caution owing to indeterminate tracking error of the system.

Table 2. *Range of Motion (* denotes hemiparetic side)*

	Horizontal (m)		Vertical (m)	
	Left Hand	**Right Hand**	**Left Hand**	**Right Hand**
Control	0.34	0.28	0.41	0.49
Subject 1	0.40*	0.58	0.40*	0.56
Subject 2	0.45	0.49*	0.60	0.50*

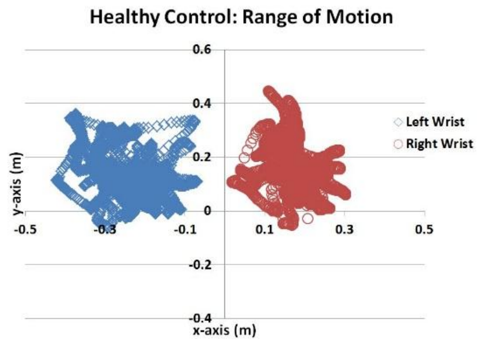

Figure 1. *Healthy control wrist range of motion.*

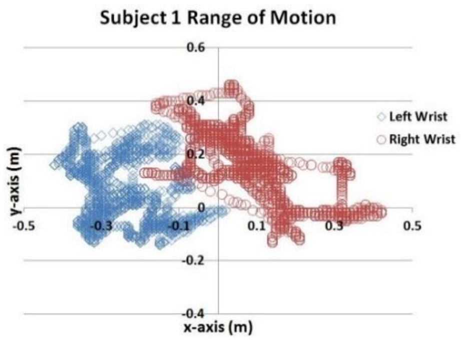

Figure 2. *Subject 1 wrist range of motion.*

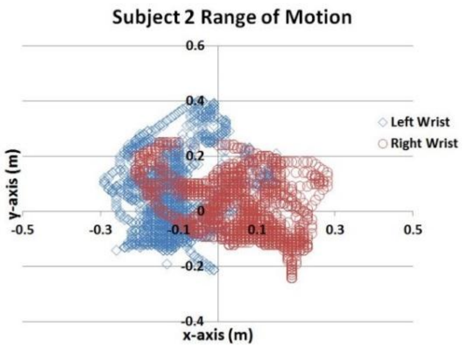

Figure 3. *Subject 2 wrist range of motion.*

3.2 Data Analysis on Directional Movement

In order to extract kinematic information related to the subjects' intended direction of motion, all movements in a game session were categorized into horizontal and vertical segments. This section presents data on the upward movement that shows subjects' trunk compensation and vertical hand offsets.

3.2.1 Trunk Compensation. Figures 4 and 5 show one upward movement trajectory for each subject. The paretic side of both subjects moved in a longer trajectory that was less straight than the unaffected side. In addition, subjects tried to synchronize both of their arms to perform a bimanual movement, evidenced by both hands stopping close to the same height. Wrist and shoulder trajectory for Subject 2 showed clear evidence of excessive trunk movement on the right side. Further 3D kinematic analysis indicated that his left shoulder moved downwards to the left and backwards, while his right shoulder moved upwards to the left and forward. No excessive trunk movement was observed in Subject 1's trajectory.

3.2.2 Vertical offsets of both hands in an upward movement. Three upward movement data sets on vertical offsets for each subject were plotted in Figure 6. Values were calculated with respect to the paretic side (i.e. a positive value means the non-paretic side was at a higher vertical position). The vertical wrist offset of Subject 1 ranged from a value close to 0 m to 0.28 m, while for Subject 2, it ranged from -0.04 m to 0.09m. Moreover, all offsets shared a similar decreasing trend with respect to motion time. This result is consistent with the discussion in Section 3.2.1, which suggests that the subjects were trying to reach the same vertical position at the end of the motion.

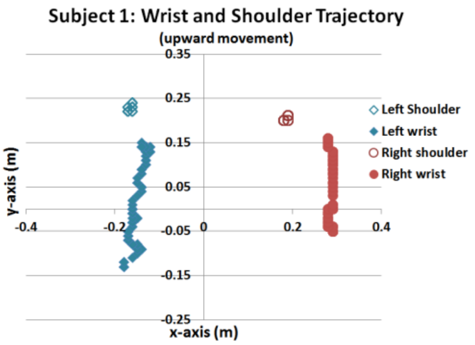

Figure 4. *Subject 1 wrist and shoulder trajectory*.

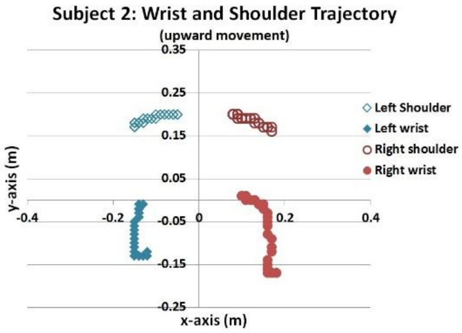

Figure 5. *Subject 2 wrist and shoulder trajectory*.

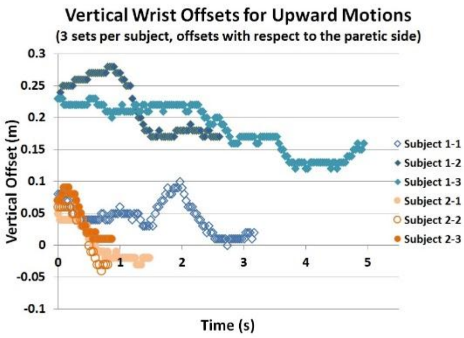

Figure 6. *Vertical wrist offsets for upward movements*.

4. CONCLUSIONS AND FUTURE WORK

Kinematic analysis of data provided by commercially available motion tracking technology could serve as an additional rehabilitation tool for therapists. While system limitations exist relative to the accuracy of gold standard motion tracking technology, this trend data can be used in tandem with clinical observations to identify variations in subjects' gross motor movements compared to healthy controls. This study demonstrates the type of data that could be provided to therapists about the quality and amount of movement during therapeutic gaming. These results will inform the next design iteration of this project to evaluate the effectiveness of a 6-month home-based treatment using the system.

Acknowledgements: We would like to acknowledge the FEATHERS team, the staff from Sunny Hill Health Centre for Children, Reality Controls Inc., Brendan Sexton, and the participants and their families.

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Integrating motor learning and virtual reality into practice: a knowledge translation challenge

S M Glegg[1], D E Levac[2], H Sveistrup[2], H Colquhoun[3], H Finestone[4], V DePaul[5], P Miller[5], L Wishart[5], J Harris[5], M Brien[6]

[1]Sunny Hill Health Centre for Children,
Vancouver, British Columbia, CANADA

[2]Rehabilitation Science, University of Ottawa,
Ottawa, Ontario, CANADA

[3]Ottawa Hospital Research Institute,
Ottawa, Ontario, CANADA

[4]Bruyere Continuing Care,
Ottawa, Ontario, CANADA

[5]Rehabilitation Science, McMaster University,
Hamilton, Ontario, CANADA

[6]Ottawa Children's Treatment Centre,
Ottawa, Ontario, CANADA

sglegg@cw.bc.ca, dleva2@uottawa.ca, hsveist@uottawa.ca, hcolquhoun@ohri.ca, hfinestone@bruyere.org, depauv@mcmaster.ca, pmiller@mcmaster.ca, wishartl@mcmaster.ca, jharris@mcmaster.ca, mbrien@octc.ca

www.bcchildrens.ca/Services/SunnyHillHealthCtr/default.htm, www.uottawa.ca, www.ohri.ca, www.bruyere.org, www.mcmaster.ca, www.octc.ca

ABSTRACT

Virtual reality (VR) systems are promising treatment options in stroke rehabilitation because they can incorporate motor learning strategies (MLS) supporting task-oriented practice. A pre-post design was used to evaluate a knowledge translation (KT) strategy supporting therapists in acquiring proficiency with VR while integrating MLS. Following e-learning modules and experiential learning, outcome measures evaluated changes in VR knowledge, attitudes, behaviours and MLS use. Improvements in therapists' behavioural control, self-efficacy, and VR knowledge were observed, though therapists used few MLS, with no improvement over time. Future KT strategies should target proficiency in VR use prior to integration of a theoretical treatment approach.

1. INTRODUCTION

VR systems are promising treatment options for physical therapists (PTs) and occupational therapists (OTs) in stroke rehabilitation because they incorporate motor learning principles of task-oriented, challenging, and motivating practice. However, documented challenges to VR system integration include limited knowledge regarding development of motor learning-based VR treatment programs targeting functional real-life goals (Glegg et al, 2013). The role of the therapist in VR is imperative for program design, monitoring, adaptation, and evaluation (Levac and Galvin, 2013). Untrained therapists may deliver sub-optimal intervention as they are unprepared to use VR systems effectively. Training support is required if therapists are to become competent at integrating VR into rehabilitation programs that transfer gains made in VR-based therapy to better functioning in the real world.

Training methods for clinicians should utilize evidence-based knowledge translation (KT) strategies to overcome the barriers inherent in adoption of these interventions (Grimshaw et al, 2012; Glegg, 2012). The purpose of this study was to develop and to evaluate the feasibility and effectiveness of a multi-faceted KT strategy to train PTs and OTs in motor learning-based VR implementation for stroke rehabilitation. The study focused on GestureTek's Interactive Rehabilitation Exercise (IREX) and Gesture Xtreme (GX) systems (www.gesturetekhealth.com, GestureTek, Toronto, ON, Canada).

2. METHODS

2.1 Participants

PTs and OTs were recruited from the population of therapists working on the stroke rehabilitation units of Bruyere Continuing Care (Ottawa, ON) and the Hamilton Health Sciences Regional Rehabilitation Centre (Hamilton, ON). Both sites provide inpatient and outpatient rehabilitation services to patients who have recently sustained a stroke. Therapists recruited patients into the study who were 0-12 months post-stroke onset and were receiving inpatient or outpatient PT and/or OT services focused on improving motor skills.

2.2 Procedures

This study utilized a pre-post design to evaluate a KT strategy. The KT strategy included the following components: *Interactive e-learning modules:* Three e-learning modules provided foundational knowledge about evidence for VR use in neurorehabilitation, neuroplasticity, motor learning principles, how VR systems can take advantage of motor learning principles, IREX/GX operation and game characteristics, and implementing motor learning strategies (such as variable practice, random practice, and promoting client problem-solving) into VR-based therapy. The format included pre- and post-module confidence logs as well as a variety of interactive activities and knowledge checks requiring learners to integrate and demonstrate their knowledge. Modules featured video clips illustrating game play as well as the implementation of MLS during VR use. *Experiential learning:* Experiential learning with the GestureTek system occurred in group and individual formats. Topics included system operation and trouble-shooting, a focus on clinical decision-making regarding selected games, and discussion about video clips of clients and therapists engaging with the VR system. Each therapist then recruited four patients and implemented 4 sessions of VR-based therapy per patient; 1 session for every second patient was videotaped for data analysis. *Audit and feedback:* Audit and feedback was provided to participants through individual practice sessions.

2.3 Outcomes

Therapist questionnaires and focus groups evaluated feasibility and effectiveness of the KT strategy. Changes in participant skill and knowledge were evaluated pre and post-study using the Assessing Determinants of Prospective Take-up of Virtual Reality (ADOPT-VR) instrument, which examines therapists' self-reported attitudes toward, as well as behavioural intention to use VR (Glegg et al, 2013). Face and content validity and responsiveness of this tool have been established (Glegg, 2012; Glegg et al, 2013). Video-Stimulated Recall (VSR), in which pre-determined motor learning competencies are scored during a semi-structured interview, and the Motor Learning Strategy Rating Instrument (MLSRI), which evaluates how therapists implement motor learning strategies during treatment sessions (Levac et al, 2013), were administered at 2 time-points (after treating 2 clients and after treating 4 clients), in order to evaluate progression in MLS skill with increased experience. The Software Usability Scale (SUS) (Brooke, 1996), which has demonstrated reliability, sensitivity and concurrent validity (Sauro and Lewis, 2012), evaluated therapists' post-use perspectives of VR usability.

2.4 Analysis

Based on non-normal distributions, non-parametric Wilcoxon signed rank tests evaluated change between pre- and post-study (ADOPT-VR) and first and second outcome assessments (MLSRI and VSR). Qualitative content analysis of focus group transcriptions was undertaken to identify benefits, challenges and common issues raised by therapists. Site 1 data was used alone in instances where site 2 data collection is ongoing.

3. RESULTS AND DISCUSSION

3.1 Therapist and client demographics

Four PTs and 2 OTs with an average of 19.3 years (SD 8.1 years) clinical experience but without previous GestureTek VR experience participated in Ottawa, providing VR interventions to 24 client participants with stroke. Client participants averaged 62.8 years (SD 16.4 years) with an average of 123.8 days (SD 166.7, range 21-682 days) post stroke Three PTs and 2 OTs in Hamilton with an average of 11.4 years (SD 9.4 years) clinical experience and without previous GestureTek VR experience who provided VR interventions to 15 client participants with stroke (mean age 60.1 years (SD 15.0 years) and averaging 131.4 days (SD 176.7, range 14-624 days) post-stroke.

3.2 ADOPT-VR, MLSRI, VSR and SUS

On the ADOPT-VR, significant pre-post improvements in therapists' perceived behavioural control (p=0.003), self-efficacy (p=0.005) and facilitating conditions (p =0.019) were observed. These changes reflect self-awareness about increased knowledge, capacity and confidence in using the system with clients, as well as perceptions of access to resources and supports necessary for VR integration, including time and technology support.

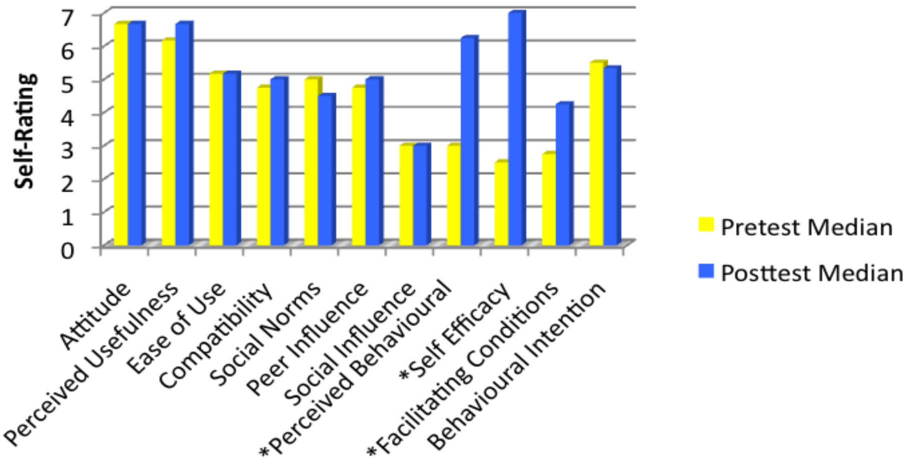

Figure 1. *Pre/post ADOPT-VR median scores (both sites) *=statistically significant difference*.

Using ICC, inter-rater reliability of the MLSRI was evaluated to be 0.80. Mean overall scores on the MLSRI at both time 1 (23.8%) and time 2 (15.8%) indicate a low observer-rated use of MLS; there was no significant change in MLSRI total (p=.281) or category scores (What Therapist Says: p= .080; What Therapist Does: p=.713; Practice: p=.197) at post-test (see Figure 2). These findings suggest therapists may have had difficulty integrating MLS into their clinical use of VR in this study timeframe.

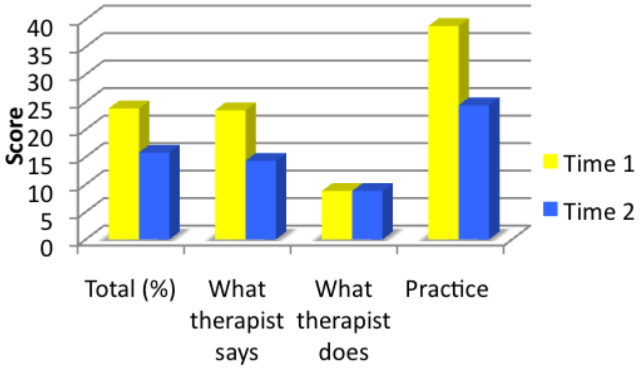

Figure 2. *MLSRI category scores pre-post (site 1).*

VSR total scores (74.4% at time 1 and 69.5% at time 2), indicate a good level of competency in therapist decision-making about VR use; no significant difference between time points was observed in total (p=.889) or item scores. These findings demonstrate early and effective integration of the VR knowledge gained, despite low perceived usability of the system, which was evidenced by an SUS mean score of 54.25 (19th percentile, below average).

3.3 Therapist perspectives

Therapists reported benefits to participating in the KT strategy, including application of the motor learning content to other areas of therapy provision. The multi-faceted methods addressed individual learning styles and were feasible within a busy clinical schedule. However, therapists were less positive about GestureTek use, reporting technical challenges with the VR equipment as well as environmental challenges with the rooms where the equipment was housed (e.g. location and size). The available games were not all perceived to be an ideal fit was difficult because available energy was expended on VR decision-making.

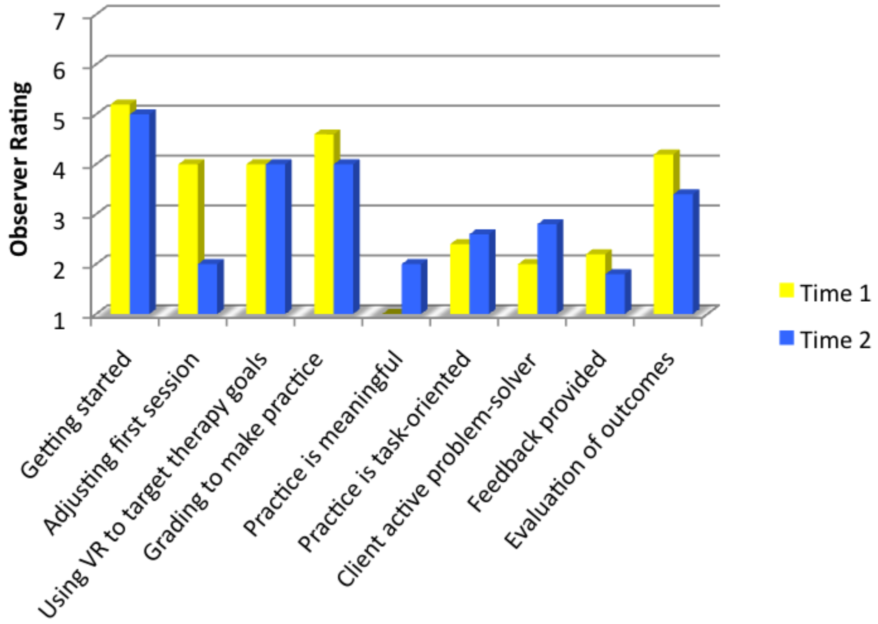

Figure 3. *Video stimulated recall pre-post item scores (site 1).*

4. CONCLUSIONS

VR integration into clinical practice can be challenging, as therapists require support to understand how to use the system to achieve therapeutic goals. A motor learning perspective is ideal given the ability of VR systems to target motor learning variables. This study was unique in evaluating the feasibility and effectiveness of a multi-faceted KT strategy that focused on both VR application and the integration of evidence-based MLS. Therapists reported benefits to the exposure to MLS knowledge beyond VR applications and were able to articulate accurate decision-making regarding VR use as measured by video-stimulated recall. Larger-scale studies using more homogenous client samples will improve confidence in the results.

Acknowledgements: This study was funded by the Ontario Stroke Network. We thank Andrew Dunn and Craig Ross at BC Children's Hospital for their contributions to e-learning module development. Dr. Levac's postdoctoral fellowship is supported by the Canadian Institutes of Health Research, the Canadian Child Health Clinician Scientist Program and NeuroDevNet.

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Assessment of motor function in hemiplegic patients using virtual cycling wheelchair

R Ishikawa[1], N Sugita[2], M Abe[1], M Yoshizawa[3], K Seki[4], Y Handa[4]

[1]Department of Electrical Engineering, Graduate School of Engineering,
[2]Department of Management Science and Technology, Graduate School of Engineering,
[3]Cyberscience Center,
Tohoku University,
6-3 Aoba, Aramaki, Aoba-ku, Sendai 980-8578, JAPAN

[4]Sendai School of Health and Welfare,
2-1-1 Akedori, Izumi-ku, Sendai 981-3206, JAPAN

r-ishikawa@yoshizawa.ecei.tohoku.ac.jp

[1-3]*www.ecei.tohoku.ac.jp*, [4]*www.sugawara.ac.jp/welfare/*

ABSTRACT

A cycling wheelchair (CWC) is a rehabilitation tool for hemiplegic patients. In previous studies, our group developed a virtual reality system that allows patients to practice driving a CWC. This study proposes a new method to estimate the torque of each leg extension of a hemiplegic patient while driving the virtual CWC. Experimental results from four healthy subjects and four hemiplegic patients showed the usefulness of the proposed method in evaluating the motor function of the patients.

1. INTRODUCTION

Stroke is a common disorder among the elderly in Japan, and it often causes paralysis of the legs. Because the population is ageing, the number of stroke patients will increase. In general, people who have difficulties walking use wheelchairs in daily life. However, while moving with wheelchairs, they do not use their legs because wheelchairs are operated by their hands or an electric motor. Typically, when the legs perform work, blood is returned to the heart. Therefore, people who do not use their legs for a long period of time risk suffering from disuse syndrome, causing muscle weakness and a fall in cardiopulmonary functions.

To solve this problem, a cycling wheelchair (CWC) has been developed and explored as a new rehabilitation tool for hemiplegic patients (Figure 1). These individuals can drive the CWC by rotating the pedals with their non-paralyzed feet. CWCs allow hemiplegic patients to move quicker and drive longer distances without fatigue in comparison to conventional wheelchairs. Moreover, they can use their hands freely while driving a CWC.

However, CWCs require patients to pedal and steer simultaneously while changing direction. Therefore, driving a CWC is difficult for patients who are not accustomed to its operation. Patients must practice driving the CWC to avoid the danger of falling and being stranded. A large and safe area is required to practice driving the CWC. Additionally, to ensure safety, assistants must be present to monitor patients using a CWC.

In previous studies, a virtual reality (VR) system was developed, which allows patients to safely practice driving a CWC, as shown in Figure 2. By applying the VR technology, patients can practice driving in a narrow place. To confirm the efficacy of rehabilitation using the system, Suzuki et al. evaluated the input torque generated by the user's legs to move the CWC. However, it was difficult to evaluate whether the paralyzed leg recovered because they were not able to extract the torque of the paralyzed leg from the entire input torque. Since the torque of each leg includes gravity effects, the influence of gravity must be considered. Therefore, it is necessary to improve the method to analyze the motor performance of the patients.

In this study, we proposed a new method to estimate the torque produced by the power of each leg separately when the user is driving the virtual CWC. To calculate the torque of each leg, we attached force sensors to each pedal. Additionally, we estimated the torque produced by the power of each leg by assuming the gravity effects and devised a new evaluation index using the estimated torque. The efficacy of the proposed method was tested experimentally.

Figure 1. *Cycling wheel chair (CWC).*

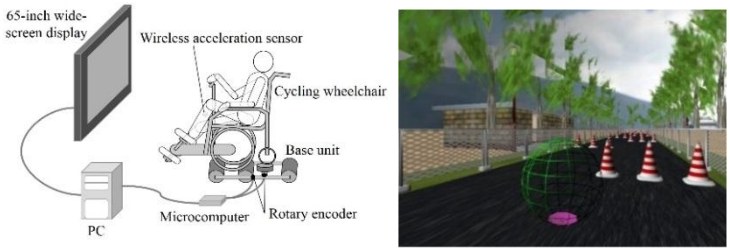

Figure 2. *Virtual reality system developed in previous study. Outline of system (left); Screenshot of VR (right)* [Sugita, 2012].

2. METHODS

2.1 Rehabilitation system

Figure 3 shows the system developed in this study. The user sits on the virtual CWC, which is fixed to the base unit, and rotates the pedals while measurements are taken. In reality, the measurement is influenced by the change in road surface conditions. Using the virtual CWC, a user can rotate the pedals in fixed conditions. The angle of the crankshaft is measured by a rotary encoder (E6A2-CWZ3C; Omron Corp.) and the data are transmitted to a personal computer (PC) using a microcomputer (Arduino; Arduino Software Corp.). To measure the forces applied to the left and right pedals, wearable force plates (M3D-FP-U; Tec Gihan Corp.) are attached to both pedals. The force plates contain three-axis force sensors, an accelerometer, and a gyroscope. To observe the change in torque produced by the user's legs, a brake system that changes the load required to drive the virtual CWC is introduced.

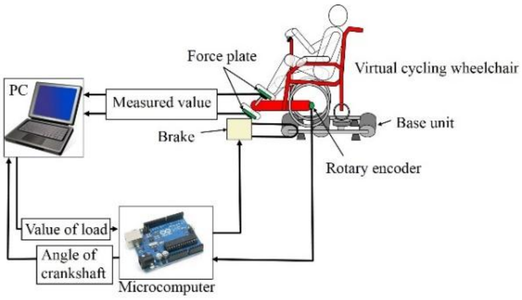

Figure 3. *System developed in this study.*

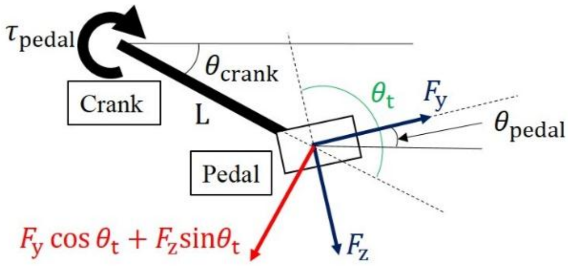

Figure 4. *Torque estimation in the pedal.*

2.2 Leg torque estimations

The torque of each leg, τ_{pedal}, is calculated using the forces applied to the pedals as follows:

$$\tau_{\mathrm{pedal}} = \mathrm{L} \times (F_{\mathrm{y}} \cos\theta_{\mathrm{t}} + F_{\mathrm{z}} \sin\theta_{\mathrm{t}}) \tag{1}$$

where F_{z} is the force perpendicular to the pedal, F_{y} is the force parallel to the pedal, L is the length of the crankshaft, and θ_{t} is the angle consisting of the angle of the pedal, θ_{pedal}, and the angle of the crankshaft, θ_{crank}. These forces and angles are represented in Figure 4. To calculate the torque of each leg, it is necessary to acquire the angle of pedal. Therefore, we use the Kalman filter.

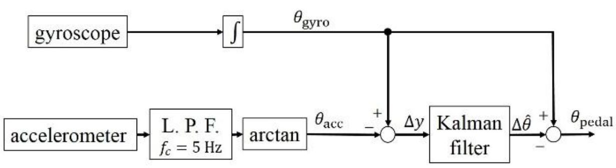

Figure 5. *Block diagram of angle measurement using the Kalman filter.*

2.2.1 Pedal angle estimation using the Kalman filter. To acquire the angle of the pedal, we applied the steady-state Kalman filter. This method uses the outputs of both an accelerometer and a gyroscope. The angle of the pedal is obtained by integrating the gyroscope outputs, and including the error caused by the offset drift of the gyroscope. Figure 5 shows a block diagram of this method, where θ_{gyro} is the angle obtained by the gyroscope

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outputs, θ_{acc} is the angle obtained by the accelerometer outputs, and Δy is difference between θ_{gyro} and θ_{acc}. We acquired θ_{pedal} by reducing the error of the angle, $\Delta\hat{\theta}$, which is estimated from θ_{gyro} using the Kalman filter. To apply this method, we determined the Kalman gains, which were required to estimate the error of the angle, using a preliminary experiment.

2.2.2 Elimination of leg gravity effects. To estimate the torque produced by the power of each leg, we must eliminate the gravity effects on the legs. The torque of the gravity effects on the leg consists of the torques of the hip, knee, and ankle joints, which are caused by the gravity effect on the thigh, shin, and ankle, respectively. Kaisumi et al. estimated the leg gravity effects by applying a model of the human leg. However, the previous study assumed that the hip and knee joints are active joints that exert torques, but the ankle joint is not. Because gravity exists on the ankle, we must consider the ankle as an active joint with torque. Thus, this study estimates the effect of gravity on the leg by applying a model of the human leg that has not only hip and knee joints, but also an ankle joint. The torque produced by the power of each leg is given by

$$\tau_{\text{human}} = \tau_{\text{pedal}} - \tau_{\text{gravity}} \tag{2}$$

where τ_{human} is the torque produced by the power of each leg, and τ_{gravity} is the torque of the gravity effects on the leg.

2.3 Index to evaluate user's motor performance

A new evaluation index using the torque produced by the power of each leg was proposed as follows:

$$\tau_{\text{left}} = \tau_{\text{lpedal}} - \tau_{\text{lgrav}} \tag{3}$$

$$\tau_{\text{right}} = \tau_{\text{rpedal}} - \tau_{\text{rgrav}} \tag{4}$$

$$T_{\text{dif}} = \frac{1}{360}\sum_{\theta=0}^{359} |\tau_{\text{left}}(\theta_{\text{crank}}) - \tau_{\text{right}}(\theta_{\text{crank}} + 180)| \tag{5}$$

where τ_{left} and τ_{right} are the torques produced by the power of the left and right legs, respectively; τ_{lpedal} and τ_{rpedal} are the torques of the left and right legs, respectively; and τ_{lgrav} and τ_{rgrav} are the torques of the gravity effects on the left and right legs, respectively. All torques are the mean values for 10 rounds of the crankshaft. T_{dif} is the difference in the torque produced by the power of the healthy leg and that of the paralyzed leg. We expect that if the motor function of the patient is recovered, the value of T_{dif} will become smaller.

2.4 Experiment

An experiment was performed to test the efficacy of the evaluation index using the torque estimated by the proposed method. Four healthy subjects (three males and one female) and four hemiplegic patients (four males; Brunnstrom stages II to IV; two right-side impaired, two left-side impaired) participated in this experiment. The age range for the healthy subjects was 18 to 22 and for the hemiplegic patients was 46 to 83. All subjects had previously used a CWC.

In the experiment, the subjects sat on the virtual CWC and rotated the pedals for 30 s. The speed of pedaling was controlled at 30 rpm. The conditions of the load were changed in two steps: 0 Nm and 2 Nm. Prior to measurement, subjects practiced pedaling at each load condition and measurement was aborted if the subject could not rotate the pedals because of the excess load. The torque produced by the power of the leg and the value of T_{dif} were calculated using MATLAB.

3. RESULTS AND DISCUSSION

All subjects could rotate the pedals at both load conditions. Figure 6 shows the mean values of T_{dif} for the healthy subjects and the hemiplegic patients. For both load conditions, the values of T_{dif} for the hemiplegic patients were larger than those of the healthy subjects. Independent t-test analysis showed that these differences are significant ($p < 0.05$). These differences occurred because the paralyzed leg was not able to generate the same torque as the healthy leg, Figures 7 (a) and (b) show examples of the torque produced by the power of each leg for the healthy subject and the hemiplegic patient, respectively. For the healthy subject, the torque of each leg is similar. However, the hemiplegic patient results show that the paralyzed leg produced a negative torque because it hardly moved and did not rotate the crankshaft. In addition, the healthy leg needed to generate a larger torque to compensate for the shortage of torque from the paralyzed leg. Thus, the value of T_{dif} for the hemiplegic patients is larger than that for the healthy subjects. The difference of the values of T_{dif} between the hemiplegic patients and the healthy subjects was larger in 2 Nm than in 0 Nm. This result is because the hemiplegic patients had to rotate the pedal on healthy leg more strongly when the condition of the load was 2 Nm. This means that applying load can estimate the motor function in more detail.

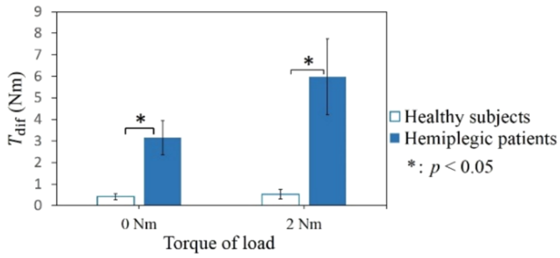

Figure 6. *Results comparison between the healthy and hemiplegic subjects.*

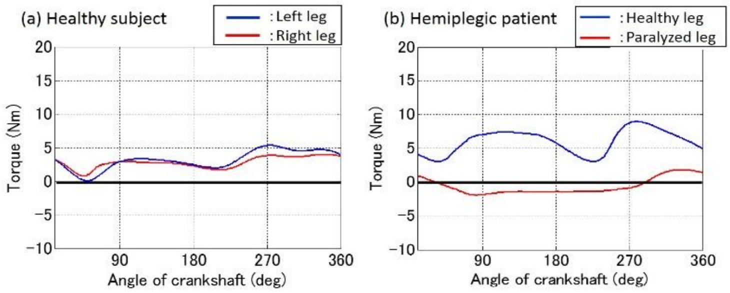

Figure 7. *Torque produced by the power of the leg for (a) a healthy subject and (b) a hemiplegic patient.*

3. CONCLUSIONS

In this study, we proposed a new method to estimate the torque produced by the power of each leg separately for a hemiplegic patient driving a virtual CWC. Moreover, we evaluated the motor function by an evaluation index using the torque, which is estimated by the proposed method. The experimental results show that the torque difference for the hemiplegic patients is significantly larger than that for the healthy subjects. These results indicate that the proposed method is useful in evaluating the motor function of the patient.

In the future, we plan to evaluate the motor function of patients driving the CWC while viewing the VR. To raise motivation for patient rehabilitation, patients must know the evaluation results using the VR. Therefore, we will develop a rehabilitation system that enables the patients to undergo rehabilitation and obtain feedback about their motor function. Moreover, we will collect long-term experimental results for the patients to evaluate the validity of the system.

Acknowledgements: The authors wish to thank the staff and patients of the Miki Hospital and the staff of TESS Co., Ltd., for their technical contributions. This study was supported by JST Revitalization Promotion Program.

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A comparison of upper limb movement profiles when reaching to virtual and real targets using the Oculus Rift: implications for virtual-reality enhanced stroke rehabilitation

M A Just[1], P J Stapley[2], M Ros[3], F Naghdy[4], D Stirling[5]

[1,3,4,5]Centre for Intelligent Mechatronics Research, University of Wollongong, Wollongong, NSW, AUSTRALIA

[2]Neural Control of Movement Laboratory, University of Wollongong, Wollongong NSW, AUSTRALIA

[1]*maj890@uowmail.edu.au*, [2]*pstapley@uow.edu.au*, [3]*montse@uow.edu.au*, [4]*fazel@uow.edu.au*, [5]*stirling@uow.edu.au*

ABSTRACT

Recent innovations in the field of virtual reality, such as the Oculus Rift head mounted display, provide an unparalleled level of immersion in the virtual world at a cost which is rapidly approaching mainstream availability. Utilising virtual reality has been shown to improve many facets of the rehabilitation process, including patient motivation and participation. These systems, however, do not enable the user to receive feedback when interacting with virtual objects, which may influence the movement profile of a patient. Therefore, to investigate how a virtual environment influences movements during stance, participants were required to reach to a real and a virtual target. Their movements were quantified using a motion capture suit, and the virtual target was generated using the Oculus Rift. The motions to both targets were compared using a number of measures calculated to characterize the velocity profiles.

1. INTRODUCTION

Virtual reality (VR) systems have been demonstrated to be applicable to many forms of rehabilitation, improving patient motivation, and overall rehabilitation efficacy. Henderson et al. (2007) found evidence that increased levels of immersion in a virtual system provide advantages in upper limb motor skill reacquisition. They concluded that high immersion added meaningfulness to exercise movements, which increased the patient's motivation and participation in training. Rand et al. (2012) demonstrated a significant increase in the usage of the affected upper extremities when using commercial video games as compared to traditional therapy. They found that providing patients with a more enjoyable and motivating experience resulted in higher frequency and intensity of movement - which is understood to be a primary contributor to the promotion of synaptogenesis, and therefore recovery (O'Dell et al. 2009).

The Oculus Rift is a ground-breaking VR device, capable of providing an unparalleled level of immersion in a virtual world. Combining the Oculus Rift with motion capture allows a user to see through the eyes of a virtual avatar, and interact with a virtual world using their movements. However, the display latency and lack of haptic feedback may cause disturbances in the velocity profiles when performing simple movements. Indeed, recent studies (Epure et al, 2014) have suggested that the use of head mounted displays (HMDs), such as the Oculus Rift, leads to a degree of postural instability.

Reaching to objects is a fundamental activity performed in daily life, and the ability to do so during standing is often diminished for the elderly or those with neurological disorders. During stance, there are significant restraints placed upon human voluntary movement, which are absent in the seated position, involving the complex coordination between movement and balance performed by the central nervous system (CNS) (Hua et al, 2013). The activation and recruitment of muscles when reaching to a real target is understood, but the effect of a non-physical virtual target is unknown. In particular, it is unknown how much perceived support humans use when reaching to fixed targets to program their movement patterns. The use of VR enables a direct comparison between fixed and virtual targets in terms of the human movements produced.

Virtual reality provides an excellent opportunity to train these skills in patients, but the differences in movement patterns that are produced when moving in a virtual world are poorly understood. This study aims to investigate the effects of VR on human movement, by comparing the underlying structure of movements (velocity profiles of the hand) during stance when reaching to real and virtual targets.

2. METHOD

2.1 Procedure

Four healthy adult male participants, three healthy adult female participants, and one stroke-affected adult male participant were included in this study, each with varying degrees of experience in virtual reality.

A physical target was set up at 1.3 times the length of the person's reach when feet are flat on the floor. The participants repeatedly reached for the target with their preferred hand, held that position for 5 seconds, retracted their hand to their chest, and held that position for 5 seconds (non-VR Trial).

The same task was performed while wearing the Oculus Rift (VR-Trial). A virtual target was placed in an environment, which was calibrated to be exactly at the same location as the physical target by having the participant reach for the physical target, then setting the location of the virtual target to the in-game location of the hand. The physical target was then removed. The only cue given concerning performance was the colour of the virtual target, which changed from green to red upon contact with the virtual avatar's hand.

2.2 Motion-Capture/VR System Setup

Participants' movements were recorded using an XSENS MVN BIOMECH inertial motion capture suit. The suit was calibrated at the beginning of each session, to ensure that the readings for the real and the virtual tests were captured using the same calibration values. Recordings were captured by the associated software MVN Studio PRO, which provides the velocity data in x, y and z directions for 23 body segments at a capture rate of 120Hz.

The motion capture data was streamed in real-time into the Unity game engine as a number of quaternion rotations, representing each segment of a 23 point kinematic map. This was then used to cause an avatar to reproduce the same movement.

The Oculus Rift HMD became the virtual eyes of the user. This HMD provided rotational information, which controls the orientation of the avatar's head in Unity, so that the user was able to freely look around the virtual world. Looking down, the user could see his/her virtual avatar's body, which was moving to match the person's own movements.

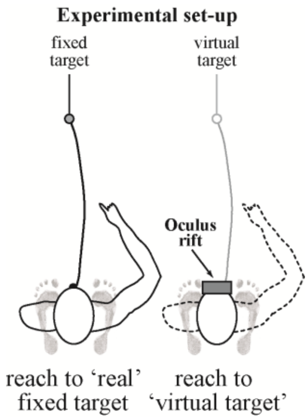

Figure 1. *Reaching to real and virtual target.*

2.3 Quantifying the Data

The motion data for each reach movement was exported from MVN Studio. Only the initial component of the reach movement to the target (fixed or virtual) was included, the motion data for return of the finger to the initial starting point being discarded. The beginning of the motion was specified as the point where the velocity magnitude of the hand reached 5% of the maximum achieved velocity.

All data sets exhibited a similar basic shape: a period of acceleration (activation) to maximum velocity, then deceleration (settling) towards the target (Fig.1).

A number of variables were extracted from the data:

1. V_{Max}. The maximum movement velocity.

2. Act_{Grad}. Gradient for the acceleration phase: how quickly the maximum velocity was achieved.
3. *Time to Target.* The time used to reach the target.
4. *Symmetry Ratio.* The ratio between the acceleration and deceleration phases
5. *Settle MSE.* The amount of variation in the settling segment.
6. *Holding MSE.* The amount of variation while holding position at the target

3. RESULTS

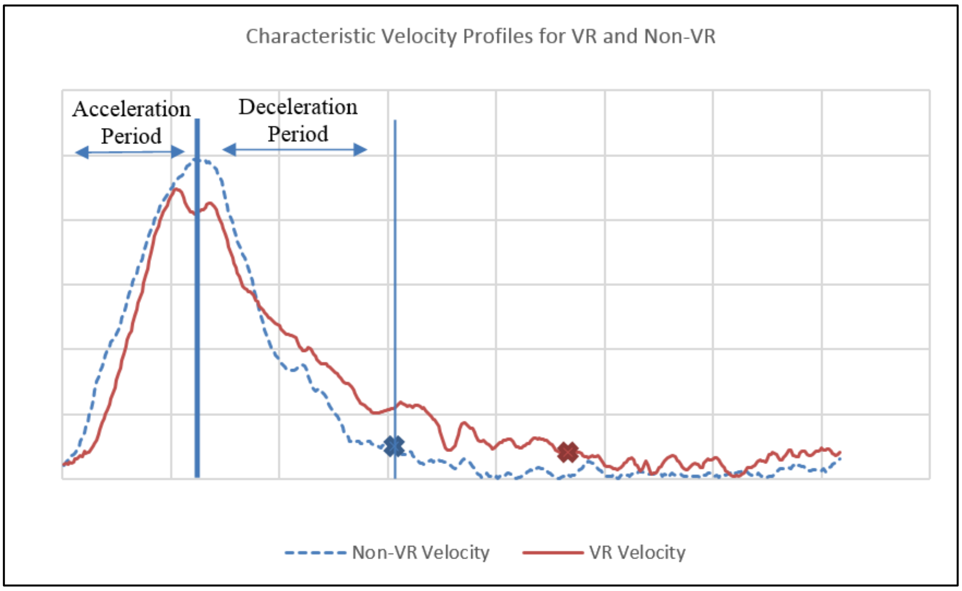

Figure 2. *Velocity profiles of characteristic results, X marks where the target was reached.*

The velocity profiles recorded showed significant differences in shape between the VR and non-VR trials (Fig.2). The time to reach the target in VR trials took, on average, 0.64 seconds longer than non-VR trials for the healthy participants, and 1.21 seconds longer for the stroke-affected participant. The VR trials showed significant oscillation during the settling period (V_{Max} to target contact) for the healthy participants, while the stroke affected participant showed a much higher level of oscillation, independent of whether it was a VR or a non-VR trial.

The MSE was calculated against a reconstruction of a stereotypical movement profile, created using the assumption that an ideal motion would accelerate and decelerate smoothly towards the target. The MSE calculated for all phases of the movement was significantly higher for the VR trials.

4. DISCUSSION

The results show that the movement profile of reaching to a virtual profile resembled that of reaching to a real target; however the deceleration phase took significantly longer, resulting in a longer time to complete the movement. The level of experience with VR did not seem to have a noticeable effect on the results, however this was the first time any of the participants had used motion capture in combination with an HMD. Participants did, however, seem to slightly improve their VR symmetry ratio over the trial, indicating that the subjects could possibly be trained through repetition so that their movements in VR more accurately resemble those in reality. This suggests that VR could potentially be used to enhance traditional movement retraining.

Upon inspection of the velocity profiles of other body segments, it was found that in general the VR movements recruited other segments significantly more that the non-VR movements. Fig. 3 shows the velocity profile of the pelvis of one of the participants over 7 reaches. The non-VR movement registered almost no activation of the pelvis, while the VR movement shows significant pelvis activation.

The fourfold increase in settling MSE indicated that subjects experienced uncertainty in the position of both their hand and the target. The lack of physical target to rest against for the 5 second hold accounted for the increased hold MSE.

Table 1. *Non-VR vs. VR results for stroke-affected participant and average of healthy participants.*

	V_{Max}	Act_{Grad}	Time To Target	Settle MSE	Holding MSE	Symmetry Ratio
Avg. Non-VR trial	**0.94**	**0.08**	**1.48s**	**0.01**	**0.0007**	**0.68**
Avg. VR trial	**0.81**	**0.02**	**2.46s**	**0.04**	**0.003**	**0.29**
Non-VR trial (stroke)	**1.18**	**0.03**	**1.76s**	**0.06**	**0.001**	**0.26**
VR trial (stroke)	**0.99**	**0.02**	**2.97s**	**0.06**	**0.003**	**0.15**

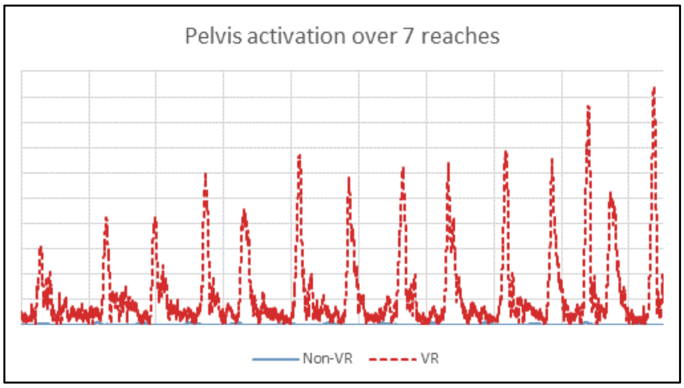

Figure 3. *Pelvis Velocity profile of 7 reaches in VR and non-VR trial.*

5. CONCLUSIONS

Differences between the VR and non-VR trials were observed. In particular, reaching during standing to a VR target required a greater degree of control of the arm during the deceleration phase than reaching to a fixed target. These results must be considered in any further research into VR-enhanced rehabilitation, particularly when utilising HMDs such as the Oculus Rift, because moving in a virtual world does not produce the same movement patterns as moving in the real world. In general, actions in VR took longer to accomplish than their real counterparts, and displayed a higher level of variance in motion, indicative of a degree of uncertainty and instability. VR movements appeared to recruit more body segments in the movement than non-VR. Further study is required to determine if these phenomena are limited to subjects inexperienced with VR, which would mean that subjects could be trained and their movements improved through repetition. Whether this effect has an impact on the efficacy of motor rehabilitation remains to be seen.

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[1]Accepted as full paper in this Proceedings: pp. 119-127 – Editor's note.

Conducting focus groups in Second Life® on health-related topics

A Krueger[1], P Colletti[1], H Bogner[2], F Barg[2], M Stineman[2]

[1]Virtual Ability®, Inc.
Aurora, CO, USA

[2]University of Pennsylvania, Perelman School of Medicine
Philadelphia, PA, USA

akrueger@virtualability.org, pcolletti@virtualability.org, hillary.bogner@uphs.upenn.edu, fran.barg@uphs.upenn.edu, mstineman@mail.med.upenn.edu

ABSTRACT

The "Mrs. A and Mr. B" research project uses focus groups conducted in the virtual world Second Life® to collect qualitative data on healthcare equitability as experienced by persons with and without disabilities. Novel methodological adaptations to traditional focus group methods include avatar consent, text discussion, participant advance preparation and disability accommodation. In this project, focus group findings are used to enrich and clarify results obtained from the analysis of a quantitative administrative dataset derived from Medicare data. In this article, advantages and challenges of using virtual world focus groups are highlighted.

1. INTRODUCTION

The "Mrs. A and Mr. B" project (www.healthcareequitability.org) examines disparities in healthcare from the perspectives of persons with disabilities. While disparities have been examined related to gender, racial/ethnic group, economic status and education level, less is known about the quality of healthcare received by persons with disabilities and the effects this has on their life outcomes. The "Mrs. A and Mr. B" project (Penn Medicine, 2013), funded by the Patient Centered Outcomes Research Institute (PCORI) in 2013, uses a mixed methods approach to address this question. A parallel mixed methods design is being used to quantify how access and quality of health care impacts the progression of disabilities and survival alongside a qualitative exploration of ways that people with and without disabilities experience healthcare in their daily lives. The quantitative portion of the study includes an in-depth analysis of ten years of administrative data from more than 30,000 adult Medicare beneficiaries. The qualitative arm of the study includes focus groups conducted in the virtual world Second Life®and in a face-to-face format. People with a wide range of disabilities add a stakeholder voice to the interpretations. The purpose of this article is to highlight the novel features of virtual world focus group functioning. Improved understanding of disparities related to disability from multiple perspectives may inform public policy and clinical practice.

2. FOCUS GROUPS IN VIRTUAL WORLDS

Traditionally, focus groups have been used in business for feedback on perceptions, attitudes, and opinions toward products or services being proposed or offered. During the introductory cycle of Second Life, when mainline businesses such as Nike and Nissan were exploring virtual worlds for traditional marketing purposes, virtual world focus groups were tried and found to be less effective than face-to-face market test groups, although some industry professionals still recommend them, with appropriate modifications. Focus groups are particularly useful when the purpose of the research is to observe in real time how participants interact around a given topic. The focus group facilitator creates a script with open-ended questions to guide the discussion. The role of the facilitator includes generating discussion, encouraging participation from all members, preventing monopolization by one individual and protecting all members from risks of breaches of confidentiality, premature disclosure or dysfunctional group dynamics. Recently, focus groups with an academic focus have been attempted in the virtual world Second Life. Stendal (2014) conducted usage studies with persons with disabilities to determine level of participation and interest in virtual worlds. Input into the Access Board's public commentary about accessibility of medical diagnostic equipment was collected from focus groups in Second Life (US Access Board, 2010). The "Mrs. A and Mr. B" project will hold 4-6 virtual focus groups regarding disability and healthcare during each of the three years of the study.

3. METHODS

A team-based approach to research involving multiple stakeholder groups is recommended in order to increase the likelihood of improving healthcare. The “Mrs. A and Mr. B” project team involves members from the University of Pennsylvania Perelman School of Medicine and the Virtual Ability community in Second Life. Stakeholders are involved in all aspects of the research. The project team has worked to adapt the focus group methodology to the virtual world setting. Novel adaptations include: tailoring focus group facilitator training to fit an on-line format in a way that accommodates all persons with disabilities, establishing recruitment and consent procedures that assure protection of confidentiality, avoid coercion and enhance opportunities for participation, and developing procedures to facilitate participation for persons with all forms of disability.

3.1 Focus Group Facilitator Selection and Training

Focus Group Facilitators are trained in the virtual world Second Life by project staff. Criteria for selection include having previous experience as a researcher using Second Life and having excellent written English language skills. Facilitators must be comfortable working with diverse people, able to think quickly in social situations, and willing to act with discretion regarding personal health information.

All current trainees and trainers are very familiar with communicating through an avatar in a virtual world, with no less than 62 months of experience. All staff participated in an online Collaborative Institutional Training Initiative (CITI) course (“Biomedical Research, Basic Course”). Facilitators received training specific to their role. Task-specific training includes generic focus group facilitation knowledge and skills for roles both as a focus group leader and as an assistant. Trainees develop knowledge of common virtual world disability-related accommodations. The final steps in facilitator training involve conducting mock focus groups with participants. The actions of the trainees are observed and evaluated by project staff. At the end of each training session, project staff debrief both the trainees and the mock participants, allowing further modification of the procedures to improve virtual world focus group processes.

3.2 Virtual World Focus Group Procedures

The project design includes both face-to-face and virtual focus groups. While these two types of focus groups cover identical content, the procedures for the two formats vary. Recruiting and consenting for participation in focus groups in Second Life is initiated through multiple means including the exchange of on-line Project Information notecards, the virtual world equivalent of text documents. The notecard presented to potential participants explains the research process and describes what research participation means to the potential focus group member. The information may also be provided orally in a group or individual setting. Project staff are available through instant messaging (IM) or email to answer questions before consent is obtained.

Potential participants give their consent by typing their avatar name of choice and the date on a notecard that is attached to the Project Information notecard. Demographic information (but not participant name) about the participant behind the avatar is maintained in a database separate from the focus group information. The necessity to obtain and type on this notecard and return it to a project staff member mitigates unintentional consent. These research protocols were approved by the University of Pennsylvania Institutional Review Board (IRB).

Focus group meetings take place in a secure location, 1000 meters in the sky above a Second Life island designated for research. (See Figure 1.) The virtual land that the meeting space is over can be made private so that only specified avatars (focus group facilitators, participants, and project staff) can enter the area. The virtual space is set up similar to a physical focus group space. (See Figure 2.)

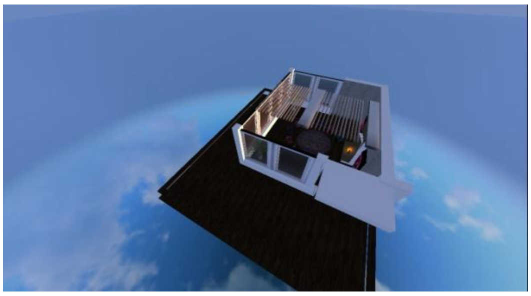

Figure. 1. *Focus Group Room floating far above virtual land surface.*

Figure 2. *Focus group session showing interior of virtual Focus Group Room and poster of topics to discuss.*

The focus group facilitator has the text of the focus group script on a notecard, from which individual segments can be copy/pasted into the text chat stream. This allows the facilitator to follow the IRB-approved script while still maintaining the flexibility to insert additional probes, clarifications, or other material as needed, akin to the flexibility of a face-to-face facilitator.

3.3 Progress to Date

As of the end of July 2014, three virtual world (Second Life) groups (11 participants) and one face-to-face group (5 participants) have been run. Transcripts from all focus groups are de-identified to remove all names and potential personally identifiable health data.

The Mixed Methods Research Laboratory at the University of Pennsylvania receives the de-identified transcripts, enters the transcripts into NVivo 10.0 software (a qualitative data management program) and applies codes to the transcripts in order to identify themes across focus groups. Initial analysis indicates emerging ideas of patients' perceptions about their healthcare. Trends include the importance of self-advocacy, the impersonal nature of doctor-patient interactions, and the lack of communication among healthcare providers indicating system fragmentation.

4. DISCUSSION AND CONCLUSIONS

Conducting focus groups in a virtual world setting requires some additional adaptations beyond those needed for face-to-face focus group facilitation. Both formats confront similar barriers: recruitment of an appropriate representative pool of participants, the need to support candor in participant responses, and concerns about privacy, confidentiality, and the potential for revealing personally identifiable health data.

4.1 Dealing with generic issues specific to virtual worlds (Second Life)

Within Second Life, it is possible to identify peer support communities of persons with disabilities from which to recruit a population similar to the population from which the quantitative Medicare data was drawn. The use of avatars to conceal actual identity has been known to increase candor (Broitman, 2007). Privacy is ensured by conducting the sessions in a physically isolated skybox. Two methods are employed to deal with concerns about personally identifiable data: collect demographic data on participants separately from their focus group contributions; and de-identify focus group transcripts before submission for analysis.

4.2 Novel features of virtual world functioning

Several significant adaptations occur because these focus groups are held in a virtual world. First, the consent process is significantly different from those in face-to-face groups, as described above in Section 3.2. Also, the focus groups are conducted entirely in text. Some individuals participating in focus groups require Americans with Disabilities Act (ADA) accommodations in order to participate. The participants experience some advance preparation.

The facilitator and participants communicate by typing rather than orally, as text is more readily accessible by most participants, including those who access their computers using assistive technologies. (See Section 3.2 above.) Individuals for whom typing or reading is impaired by their disability request accommodations ahead of time. We assign a typist for persons wishing to give their input orally. Similarly, a reader is assigned to persons who cannot see or read aloud the text chat. These helpers are all CITI certified.

Participants are given a notecard with the questions to be addressed when meeting arrangements are made. They are encouraged to type out responses to these questions on the notecard in advance, so that they can easily copy/paste them as appropriate. Of course they can also then type additional comments or responses to what others shared. Advance preparation accommodates those for whom typing is laborious, or who require additional time to think through their responses. It also allows more time for discussion, since spontaneous typed responses take more time to transmit than do spoken responses. Moreover, responses prepared in advance can be submitted after the focus group has been completed so that ideas that did not have a chance to emerge during discussion may still be captured.

4.3 Advantages of conducting focus groups in virtual worlds

The advantages and disadvantages of collecting qualitative data through face-to-face focus groups are well documented. Virtual world focus groups have somewhat different advantages and disadvantages.

For the "Mrs. A and Mr. B" project, the major advantage of conducting focus groups in a virtual world is that it allows much easier access to our target audience—people with disabilities. People with disabilities make up a significant portion, perhaps as high as 20% (Information Solutions Group, 2008), of those in virtual worlds. In virtual worlds, they can participate more freely in public events such as focus groups. In a virtual setting, they do not face logistical issues to attend meetings, such as transportation or the need for meeting organizers to provide medical or assistive technology equipment. Additionally, international participation is much easier, and the facilities for conducting research in virtual worlds are inexpensive. The existence of dialog as text is helpful, as no transcription is necessary.

4.4 Disadvantages of conducting focus groups in virtual worlds

One disadvantage of conducting focus groups in a virtual world is that the population accessed must be both computer literate and possess a high-end computer. This population is not representative of disabled people at large, nor is it representative of the population in the Medicare administrative dataset that we are using in the quantitative arm of the project. To mitigate this in the "Mrs. A and Mr. B" project, we include face-to-face focus groups with members of an urban community who have lower literacy skills and are not computer users.

Avatars do not provide nonverbal information such as gestures or tone of voice. These sources of information, often gleaned from face-to-face focus group meetings, are missing, but with the topic we are interested in, we feel that this is less important than the text content.

4.5 Conclusion

Overall, the advantages of using virtual world focus groups outweigh the disadvantages. People with disabilities like to help others and wish to give back to their communities. Many participants welcome the ability to be able to be heard in a forum in which issues about which they care deeply are discussed. The focus groups held in Second Life effectively involve them in academic research. The "Mrs. A and Mr. B" project is demonstrating the utility of this novel method of collecting qualitative healthcare data.

With increasing use of virtual worlds for product design, testing, and prototyping, as well as educational and therapeutic endeavours, collection of data by focus groups in virtual worlds will also increase. To fully leverage the unique affordances of a virtual world setting, typical face-to-face focus group protocols must be modified (Houliez and Gamble, 2012). Therefore our experiences with focus groups for the "Mrs. A and Mr. B" project can help improve the quality of data collected in future virtual world projects.

Acknowledgements: This project was funded by the Patient-Centered Outcomes Research Institute (PCORI), PCORI contract number AD-12-11-4567.

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Physically accurate velocity distribution profiles for use in virtual reality training for prosthetic limbs

P Kyberd[1], R Bongers[2], S Hamza[1]

[1]Institute of Biomedical Engineering,
University of New Brunswick, Fredericton, CANADA

[2]Centre for Human Movement Sciences, University Medical Center Groningen, University of Groningen, Groningen, THE NETHERLANDS

pkyberd@UNB.CA, R.M.Bongers@umcg.nl

ABSTRACT

Virtual reality has been used in many areas of application, from training to simulation. There is an increasing interest in using VR for training persons for prosthetic limb control. In a prosthesis, a myoelectric signal map to the velocity or position of a prosthetic joint. There is little evidence on what is the appropriate mapping between the myoelectric input and the prosthetic joint output. There is a possibility that a poor mapping will hinder the training. This study is the first stage in the process to understand this mapping, by studying the distribution of velocities in the intact arm in a conventional Fitts law test. What is observed is a wide range of velocities, decreasing in frequency as the velocity increases. This implies that for VR training to be effective a wide range of velocities need to be used in that training.

1. INTRODUCTION

Virtual reality has been used increasingly in many areas of application, from training to simulation. If it is used for training and is in the form of a game, it is important that the tool encourages the correct behaviours to ensure the subject is trained in a way that improves their performance, rather than increases their facility to play the game.

1.1 Control of prosthetic arms

Externally powered artificial arms use Electromyograms (EMGs) as control inputs, these are the electrical signals associated with muscle contraction (Muzumdar, 2004). They can be used to instruct a joint to flex or extend. The amplitude of the signal is mapped to a control signal in the prosthesis. This mapping is usually to the velocity of the motor (occasionally to joint position). Thus the velocity of the device and how it is controlled is an important factor when designing the control system, or simulating it for training. However little is known about the velocities used or what is the most appropriate mapping. While the relationship between muscle contraction and EMG amplitude is not precise, the user feels that the speed of the limb reflects the level of contraction of their commanding muscles. This control is not particularly natural and needs to be trained. Simple computer games have been employed for many years to train users of prosthetic limbs to control their artificial arm. To engage new users of prosthetic limbs, an aspect of play in the training is useful. Historically, the games written by the manufacturers of commercial prosthetics limbs have been extremely simple, low resolution and two dimensional, no more recent games have been written with the express purpose of training EMG control. With the increasing availability of high definition, fast action, computer games, these earlier tools increasingly look old fashioned and anecdotal experience in the clinics, show that they fail to engage modern users for very long. It is therefore useful to design games that engage the potential user more fully. However the task of matching the game to the needs of training have not been addressed. This study looks at a single aspect; the dynamics of the control input.

The question addressed is: *What should the mapping be between the contraction of the command muscle and the movement of the prosthesis?* If the motion is too slow, use may be tiring and frustrating and may result in the rejection of the prosthesis, but if the motions are too fast then the limb may be uncontrollable. If a VR is used to train the user and it has dynamics too different to that of the actual system it is conceivable that the user will have to unlearn their training before using the prosthesis well, and this too may cause them to reject the prosthesis. So being able to determine what simulation is sufficient to engender the correct response is an important part of the process of designing a training VR for prosthetic limbs.

Control of a prosthetic limb involves the placing the hand or fingers in the correct position to handle an object. The user is only interested in the simplicity of the control of the motion which is the combination of the speed of motion and the ease of control input. So it is important to know *how* the arm moves as it is used, that is, the *distribution of velocities* throughout the motion.

1.2 Velocity distribution in upper limb activities

A survey of the literature produced no objective evidence as to what are the distribution of velocities of natural limb motion in everyday life. Specifically, the literature focuses is on particular aspects of control, or the movements, positions or instantaneous velocities. Studies do not explicitly discuss the *range* of velocities a joint goes through for any specified task, simply peaks, profiles or angles (Bongers 2012, Andel 2008). Additionally no study has been made of the velocity distributions of proportionally controlled prosthetic limbs. Thus the purpose of this study is to understand natural kinematics of the human arm to allow comparison with the movement of a prosthesis in later studies. The starting point for this is the simplest task, to examine a simple pointing motion and observe the velocity distribution.

A model for human control is Fitts' law (Fitts 1954), this studies the way that a person will move between two points and is concerned with the trade off between speed and relative difficulty of the task. When the subject moves between two points they match the speed to the task. For points further away the subjects move faster, for targets harder to achieve (smaller) they slow the rate to ensure an increased level of precision. It has been used study a variety of applications; from operating a computer mouse, to measuring the use of pattern recognition of electromyograms in prosthesis control (Soukoreff 2004, Scheme 2014).

2. ANALYSIS OF VELOCITY DISTRIBUTION

2.1 Methods

2.1.1 Simulation. The implication of Fitts' law is that if a participant moves a limb (or part of a limb) between two points (for example a pointing task) their arm will accelerate to maximum speed for the majority of movement, to decelerate rapidly when the target is neared. So the distribution of velocities would have two peaks at low speeds and the maximum velocity (determined by distance and level of difficulty). This motion was simulated for a Fitts law test with a single difficulty Figure 1(a). Since it is the *distribution of the velocities* that is of interest in this study, the distribution was also calculated, Figure 1(b). The motion was a single symmetrical curve with 3000 time steps. The velocities are divided into 181 bins of size 0.006, and the number of instances counted across the movement. This result is for a single distance and single difficulty. However, the current study is concerned with motions in general activities, with varied distances, speeds and difficulties. This situation is simulated with performing the distribution analysis on five simulated motions, with the same distances to the target (Figure 2). This is then compared with data from an experiment on able bodied subjects.

2.1.2 Experimental data. Data was taken from an experiment designed to observe the use of upper limbs and was analysed to reveal the velocity distributions of the limb (Bongers 2009). Subjects used a tablet and moved a pointer between two points. Ethical approval for the original experiment, was received. Approval allowed the further use of anonymised data, only subject number, gender, age group (young or adult) and experimental group was used.

Each session began with a practice trial. There were six different distances and four levels of precision (difficulty), totalling 24 conditions, and ten subjects. For the purpose of this study, the velocity profiles for all conditions were analysed. The subjects were, five men and five women, ages 20 to 54. All participants were right-handed and had normal or corrected to normal vision. The movements were made with a stylus on a Wacom Ultrapad A3 graphics tablet (Wacom Company, Tokyo, Japan). Stylus movement was sampled at a frequency of 170 Hz. The movement times had six levels (200, 300, 600, 900, 1,200, and 1,500 ms) and four distances between the target lines (5, 10, 20, and 30 cm).

2.1.3 Data analysis. Position data of the pointer was inferred from the tablet. The velocity of the pointer was then mathematically differentiated to obtain the velocities of the pointer. The velocities were then divided into bins and the frequency of each bin counted and the results plotted, data was then pooled.

2.2 Results

2.2.1 Simulated data. Figure 1(a) shows the velocities of the simple motion of the pointer, the curve is bell shaped. Figure 1(b) shows the distribution, which is a bimodal curve with a peak at low speeds (close to stopped), and another peak at the maximum, with very few instances at other speeds, as was predicted.

Proc. 10th Intl Conf. Disability, Virtual Reality & Associated Technologies
Gothenburg, Sweden, 2–4 Sept. 2014

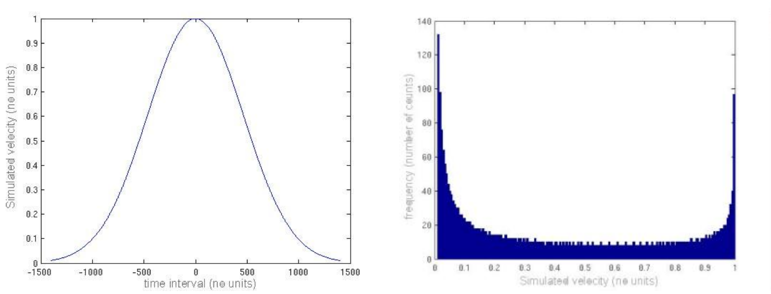

Figure 1. *(a) - Simulated velocity of a hand moving between two points in one plane. Velocity is normalised to a maximum of 1. (b) Velocity distribution of 1(a). The velocity is divided into bins of (181 bins) of size 0.006, instances of each velocity is then plotted.*

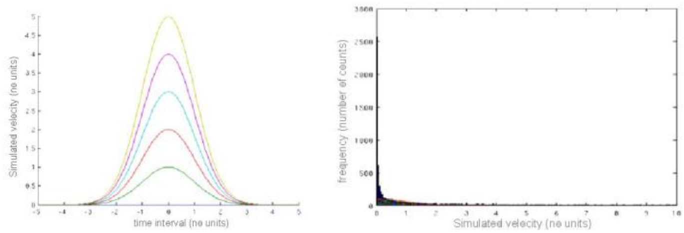

Figure 2. *(a) Range of velocities simulated, maximum velocities at integral values from 1 to 5.(b) Cumulative velocity distributions from 2(a). Bins are the same as 1(b). The distribution is now a single peak at zero velocity and a monotonic drop in higher velocities.*

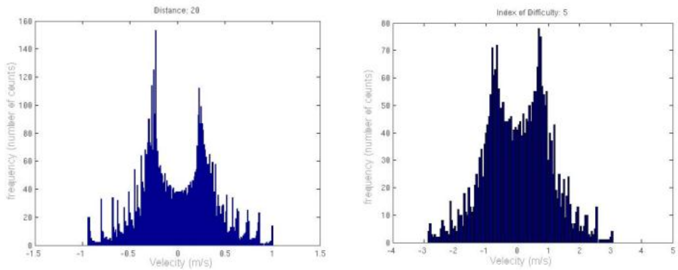

Figure 3. *Velocity distribution analysis of one inter-target distance (20cm) (Bin size 0.01) and one index of difficulty (5 for the Fitts' law experiment.*

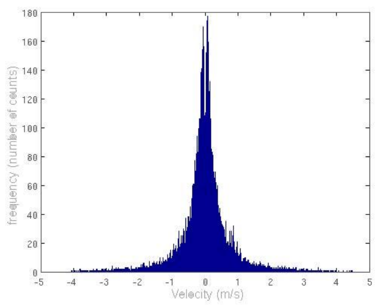

Figure 4. *Velocity distribution analysis all of the data from the Fitts' law experiment. What is revealed is peaks around zero velocity and a drop off as the recorded speeds increase. Bin size 0.001.*

Figure 2(a) shows the 5 different curves for different difficulties, i.e. that the subject would move more slowly as they became more careful to achieve the target. Figure 2(b), shows a curve with a single peak at zero and increasingly fewer instances of the higher velocities. If the test was conducted with motions in two directions (forward and back) then the curve would have a single peak at zero and monotonically falling off both in the positive and negative directions.

2.2.2 Experimental data. Figure 3 shows the velocity profiles for two of the instances of the experiment; each are one distance and one level of difficulty. The result is peaks at the maximum speeds (positive and negative) and fewer instances of intermediate speeds. For the original experiment; increasing distance resulted in increasing maximum speeds, and increased difficulty with reduced velocities. When the data from the entire experiment was pooled, with six distances and four levels of difficulty (24 groups), the bimodal nature disappears and a monotonic distribution becomes apparent, figure 4.

2.3 Discussion

Experiments to investigate the control of the natural limb are designed to isolate one aspect of human control for analysis. However, the regular use of the arm in daily activities is much less structured or closely confined. If prosthetic training is to reflect the real use of a prosthetic limb, then it must reflect the velocity distribution that the prosthetic arm experiences. For best control designers need to understand what compromises they make when they design a prosthesis system, this can only come from a position of knowledge. When designers and engineers are informally asked to reflect on what the distribution of velocities of a prosthetic arm during activities of daily living, they tend to predict a bell shaped curve; subjects accelerate to a maximum speed and continue until close to the target when they stop. From this it would seem that there is little consideration to the different speeds that might result from different tasks. It is likely that designers would tend to assume that there is little need to control the arm at speeds other than at maximum for transport and at slow speed, for close manoeuvring, but an arm controlled this way may be very hard to use. Thus as designers are not in a position to state what are the velocities used in natural manipulation and if the prosthesis controller (and hence training tool) needs a greater range of velocities. This analysis shows that the variations that underlie the Fitts law concept mean that over a range that reflects natural grasping is a different distribution, one where the frequency of the instance of a velocity decreases as the speed increases.

The next stage of this investigation will be to observe both unimpaired subjects and prosthesis users to determine if these finding reflect the velocity distribution in unconstrained tasks.

3. CONCLUSIONS

Motions over a wide range of distances and difficulties result in a distribution of velocities where there is decreased likelihood of a particular velocity as the speed increases. This implies that no velocity is more significant than any others. This suggests for a VR simulation for the purposes of training myoelectric prosthesis users, care should be given to the choice of the dynamics of the game.

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Perception of multi-varied sound patterns of sonified representations of complex systems by people who are blind

O Lahav[1], J Kittany[1], S T Levy[2], M Furst[3]

[1]School of Education, Tel Aviv University, ISRAEL

[2]Faculty of Education, University of Haifa, ISRAEL

[3]Faculty of Engineering, Tel Aviv University, ISRAEL

lahavo@post.tau.ac.il

ABSTRACT

Listening to Complexity is a long-term research project, which addresses a central need among people who are blind: providing equal access to the science classroom, by allowing them to explore computer models, independently collect data, adapt and control their learning process. The innovative and low-cost learning system that is used in this project is based on the principle of perceptual compensation via technologies, by harnessing the auditory mode to transmit dynamic and spatial complex information, due to its unique affordances with respect to vision. Sonification of variables and events in an agent-based NetLogo computer model is used to convey information regarding both individual gas particles and system-wide phenomena, using alerts, object and status indicators, data representation and spatial audio displays. The paper describes two experiments: (1) Auditory perception of varying types of auditory representations, spatial trajectories of a modeled object's motion, relative intensity, and frequency; and (2) Auditory perception of complex sound patterns – exploring detection and recognition of multiple sound channels at different complexity levels of sound patterns. The research would serve to improve our understanding of the auditory processes by which perception of sound patterns takes place and transforms into a conceptual model. The long-term practical benefits of this research are likely to have an impact on science, technology, engineering and mathematics education for students who are blind.

1. INTRODUCTION

1.1 Science Education for Students who are Blind

The project addresses a central need among students who are blind: accessing information in exploratory learning of science. Students who are blind have been integrated into public schools for more than 60 years and are required to complete the same curriculum and assessments as sighted students. However, they are prevented from access to firsthand information, as many science education resources are based on the visual channel (Beck-Winchatz and Riccobono, 2008). In the past 40 years several manuals have been written on how to teach science to students who are blind and visually impaired (Hadary and Cohen, 1978; Kumar et al, 2001; Willoughby and Duffy, 1989). However, research into their application and impact on learning is sparse (Zaborowski, 2006). Few learning environments based on assistive technologies have been created to support science learning, such as the use of a force-feedback mouse to learn physics (Farrell et al, 2001; Wies et al, 2001).

1.2 Auditory Information Technologies for People who are Blind

The learning process of people who are blind is based on gathering information through perceptual and conceptual tools (Passini and Proulx, 1988). At the perceptual level, the shortage in visual information is compensated for by other senses such as the haptic, auditory and olfactory senses. Similar to other supportive environments, the Listening to Complexity (L2C) system is based on the principle of perceptual compensation via technologies (Lahav and Levy, 2010). L2C harnesses the auditory mode to transmit dynamic complex information. The choice of an auditory display results from three considerations: (a) the auditory mode transmits information that changes both in space and time, similar to the visual mode and different from the haptic mode; (b) the auditory mode easily interfaces with large bandwidths at fine frequency-discrimination and intensity-discrimination thresholds (Capelle et al, 1998); (c) the auditory system is used to dealing with complex and rapidly changing sound patterns (Hirsh, 1988). In fact, it has been found that individuals who are blind can recognize 2D shapes through audition that activates the right dorsal extrastriate visual cortex (Collignon et al, 2007). Sonification is the presentation of information using non-speech sound (Kramer, 1994).

Over the years, it was found that congenitally blind subjects were able to recognize auditory coded visual patterns related to hand movement (Arno et al, 2001). Subjects not only memorized simple associations between sounds and patterns; but they also learned the relationship between the auditory code and spatial attributes of the patterns. Research into the impact of different components of sound on auditory perception has shown that increasing the number of channels beyond three causes degradation in comprehension (Stifelman, 1994) and that a greater frequency separation between sound streams results in better stream segregation (Bregman, 1990). In the current project, we go beyond these studies in several ways. On one hand, we use sound to represent a dynamic rather than a static array. Moreover, the referents of the dynamic representation are multiple and operate at two system levels. Finally, we test how systematic variation of several different sound pattern features impacts detection and recognition of multiple channels, extending research into auditory perception. Few systems were developed to support Science, Technology, Engineering and Mathematics (STEM) education among students who are blind, such as the Talking Tactile Tablets (Landau et al, 2003) based on audio and 2D tactile materials, supporting interaction with 2D images for learning mathematical and science diagrams. The Line Graphs technology is based on auditory and haptic feedback and is geared to learning mathematics (Ramloll et al, 2000). The reported studies continue research into auditory compensation for visual information among students who are blind and extend it to both perception of dynamic and complex displays and learning about dynamic complex systems. The two experiments tackle a major challenge and require a leap above the current state-of-the-art in several research disciplines such as Computer Science, Learning Sciences, Auditory perception, and Human-Machine Interaction. We seek a deeper understanding of the neuroscientist Bach-y-Rita's phrase on brain plasticity: 'We see with the brain, not the eyes' (1972). To reach this overall goal we focus on two main experiments:

1. Auditory perception of varying types of auditory representations, the spatial trajectory of a modeled object's motion, relative intensity and frequency of sound.
2. Auditory perception of complex sound patterns, varying the number of sound streams, identity of the sonification components, their number, relative intensity and frequency.

2. METHODS

2.1 Sample Selection

The study included ten participants selected through snowball sampling for both experiments. A severe limitation is the small number of blind students in the proposed age bracket in Israel, resulting in a relatively small sample. They were chosen based on six criteria: at least 15 years old; comfort in use of computers; not multi-handicapped; normal hearing; total blindness; and onset of blindness at least two years prior to the experimental period. The participants' age range was 15-36, an average of 24 years old, five participants were female, eight were congenitally blind, five participants had residual vision but none used this in their everyday life. All the participants are proficient computer users, all learned STEM in their preliminary and high schools. All participants were with normal hearing, four participants played a musical instrument and one was member in a choir. The researchers obtained a sample of ten students, with similar proportions in terms of gender, age, and musical knowledge. The consenting guardians were made fully aware of the research framework and the specific experiments.

2.2 Variables

Nine Independent variables were defined, first three variables are connected to the research participants: age of onset of blindness; gender; and musical background. The next three variables are related to Experiment One: sonification type (musical instruments, inanimate objects' sounds, man-made sounds, and animal's sounds); spatial trajectory of the modeled object's motion; and sound frequency. The last three variables are associated with Experiment Two: sound intensity (loudness); Complexity of sound pattern (event frequency and complexity); and number and type of sound streams. Three dependent variables are defined: Preferences among sonified representations (Rating of the pleasantness of the sound, Most disliked (1); Dislike (2); Neutral (3); Like (4); and Most liked (5)); response time; and error rate in sound pattern recognition

2.3 Research instruments

This research included four implementation tools, and four data collection tools. The four implementation tools were the following: (i) Research apparatus - the recorded sounds were played through an Excel file running under Windows 7 on a personal computer equipped with stereo headphones (Sennheiser, HD580). All the sounds were played in 50% of the PC volume capability; (ii) Set of sound patterns Experiment One: a set of 31 sound patterns, developed with experts of dynamic sound patterns: object-object collision (7), object-wall collision (7), speed was represented in three different ways – dashed speed represented speed by creating sound at regular distance intervals resulting in more frequent sound when the object was faster (4), sound pitch-as-speed, with pitch height representing speed (4), pitch space speed represented is base on the stereo sound (right left) and intensity (loud-close, soft –far) according to the speed and the particle's location in the space (4), each of these representations with varied frequency (5). All the sounds were based on earcon (associative auditory feedback used to represent an event), or created by the computer's MIDI musical instruments, or recordings of inanimate objects' interactions and man-made sounds, or animal sounds. For example: object-object collisions were represented with the a hand clap; air bubbles passing through water; glass tapping on glass; metal tapping on metal; billiard ball hit by the cue. We examined these sounds at five different frequencies: 500; 1000; 2000; 4000; and 5000. This set of sounds meets requirements regarding frequency range (500-5,000 Hz) and loudness (75dB) with respect to sensitivity of the human auditory system, duration (200 millisecond), wave structure, 16 bit per sample, and stereo stream; (iii) Sound tests for Experiment One: all the 31 sound patterns were tested twice by using different recorded scenarios in two different tests: comparison tests (e.g., which sound is preferred to represent speed? Sound A vs. Sound B) and scale - preferences among sonified representations (Most disliked (1); Dislike (2); Neutral (3); Like (4); and Most liked (5); and (iv) Sound tests for Experiment Two: based on results from Experiment One five sound representations were chosen for Experiment Two. 36 combinations of these five sounds were created, meeting the requirements regarding frequency range (4,000 Hz) and with respect to loudness sensitivity of the human auditory system (75dB), duration (30 second), wave structure, and stereo stream. In addition to the above, four tools was developed for the collection of quantitative and qualitative data: (i) Background questionnaire (15 items): personal information, science education, computer technology use, musical background, and information about hearing ability; (ii) Research protocol: two research protocols were developed, one for each experiment. These were structured as described in the procedure section hence. The Research protocol for Experiment One included five parts: explanation about the research; researcher demonstration; practice and training by the participant; experiment (part 1); intermission; experiment (part 2). The research protocol for Experiment Two also included five parts: explanation about the research; researcher demonstration; practice and training by the participant; experiment (part 1); intermission; and experiment (part 2); (iii) Observations: participants' behaviors were video-recorded (Experiment Two only); and (iv) Excel file structuring and accessing the design of the sounds in the research protocol.

2.4 Data Analysis

To evaluate the participants' performance in the two experiments, the results were coded directly by the researcher into an Excel file. These results were analyzed using quantitative software (Excel) to determine the relative preferences regarding sounds for each referent.

2.5 Procedure

All participants were examined individually in their home. In the first session the participants completed consent forms and a background questionnaire. Next, they were tested with Experiment One. After six months they were tested with Experiment Two. Each experiment included five parts: a short verbal explanation about the experimental process; researcher demonstration; practice and training by the participant; experiment part 1 (20 minutes); intermission (30 minutes); and experiment part 2 (20 minutes). Each of these protocols was conducted twice, 1 to 2 weeks apart.

3. DISCUSSION

In the described experiments ten participants took part in two experiments: Experiment One, auditory perception in which auditory representations were varied along various dimensions and Experiment Two, auditory perception of complex sound patterns, recognition of the sonified referents. The results of these experiments have important implications for continued research, and impact learning of people who are blind learning via sonified learning materials. Some of the Experiment One results highlight the importance of sonifying with sounds that are semantically related to the referent. For example, billiard ball collisions were preferred for sonifying object-object collisions (two billiard ball (same material) collide with each other) with respect to glass tapping on glass. The Navajo drum-beat was preferred for representing the object-wall collisions (an object (one material) collides with a wall (leather drum-head)). The participants didn't select animal or digital sounds and preferred recorded real life objects with related meanings. Also, as a speed representation, most of the participants selected the dashed sound, for which frequency of the dashes corresponds to the speed, and not the pitch-space sound that requires additional cognitive processing for aligning the representation (pitch) with the referent (speed). The 2x2 methodology, using the two sessions (data collection sessions) with two tests (comparison and scale tests) aided the researchers in reliably determining the selected sounds. By the time of the conference, the results from the second experiment will be analyzed and presented and further statistics analyzing of the first experiment will be added (such as *t*-test, χ^2, and cross tabs). Finally, we test how systematic variation of several different sound pattern features (type, number of audio streams, correctness of sound pattern recognition, and auditory perception tools) impacts detection and recognition of multiple channels, extending research into auditory perception, furthering support of the learning process of people who are blind that is based on auditory feedback.

Acknowledgments. This research was partially supported by a grant from The Israel Science Foundation (ISF) Individual Research Grant (2011-2015). We thank our anonymous participants for their time, efforts, and ideas.

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Adaptation of postural symmetry to an altered visual representation of body position

M Lemay[1,2], L-N Veilleux[2], M Marois[2], L Ballaz[1,2], DM Shiller[3]

[1]Département de Kinanthropologie, Université du Québec à Montréal,
C.P. 8888, succursale Centre-Ville, Montréal, Québec, CANADA

[2]Centre de réadaptation Marie Enfant (CHU Sainte-Justine)
5200 Bélanger est, Montréal, Québec, CANADA

[3]École d'orthophonie et d'audiologie, Université de Montréal,
7077 Ave du parc, Montréal, Québec, CANADA

lemay.martin@uqam.ca, lnveilleux@shriners.mcgill.ca, mikael.marois@polymtl.ca, laurent.ballaz@uqam.ca douglas.shiller@umontreal.ca

ABSTRACT

The goal of the present study was to determine whether postural symmetry can be altered through sensorimotor adaptation. A gradual change in postural symmetry was induced in participants by biasing visual feedback of their body's center of pressure toward the left or the right. Results showed that this procedure induced a significant shift in participants' stance, which resulted in postural asymmetry and altered postural control that persisted beyond the period of altered visual feedback. We discuss the implications of such visuo-motor procedures for the rehabilitation of patients with postural asymmetry.

1. INTRODUCTION

Postural control requires continuous processing and integration of feedback from the visual, vestibular and somatosensory systems in order to minimize body sway (Fitzpatrick and McCloskey, 1994). The body center of mass is kept within the base of support through displacements of the center of pressure (COP), which is the point location of the vertical ground reaction force vector. When both feet are on the ground, the net COP tends to lie at a central location between the two feet (Winter, 1995). However, in some patients with unilateral neurological or musculoskeletal deficits, COP deviates from the center of the base of support leading to an asymmetric posture (Shumway-Cook and Woollacott, 2007). These patients maintain more weight on the non-involved leg, which may affect postural control and gait (Ring and Mizrahi, 1991). In these patients, a correction of postural alignment may be required to reduce the risk of falls (Di Fabio and Badke, 1990) and avoid long term musculoskeletal complications such as back pain.

The goal of the present study was to examine the capacity to modify postural alignment in healthy participants using a sensorimotor adaptation paradigm. During sensorimotor adaptation, sensory feedback (e.g., visual or proprioceptive) is manipulated in real-time, and compensatory changes in motor output are examined following a period of practice under such conditions. Numerous studies of sensorimotor adaptation during pointing movements have been carried out in healthy participants, involving visual manipulations (ex. prismatic adaptation) or externally applied force-fields (e.g., Bhushan et al, 2000; Kennedy and Raz, 2005; Martin et al, 2002; Nakajima 1988; Pisella et al, 2006). The results from these studies indicate that the motor system is highly adaptive to changing sensorimotor conditions. However, to our knowledge, this paradigm has never been tested in the context of whole-body postural motor control.

2. METHODS

2.1 Participants, experimental setup and procedures

Twenty healthy participants were tested (20-33 years of age). Participants reported no history of motor or sensory disorder. All participants were asked to stand on a force plate (Advanced Mechanical Tech Inc., Watertown, MA, USA) with their feet parallel to each other (at shoulder width) and arms relaxed at their sides. Markers were affixed to the force plate along each foot to ensure that participants maintained the same position throughout the test. The experimental procedure consisted of three phases: 1) the *Adaptation* phase involving postural movement under normal and altered visual feedback conditions, 2) the *No-feedback* condition, involving postural movement with no visual feedback, and 3) the *Wash-out* phase, involving postural control under normal visual feedback conditions. In order to evaluate the changes in postural alignment induced by the Adaptation and Wash-out phases, participants performed one minute of quiet standing (standing still on the force plate while fixating a visual target) at three time points: immediately prior to the Adaptation phase (baseline value), immediately following the Adaptation phase, and immediately following the Washout phase. Postural alignment was determined by computing the foot center of pressure (COP) reflecting, at each moment, the spatial position at which the sum of forces exerted by the body acts on the force plate.

Visual feedback was provided to participants on a 46" screen (2m distance), including a box representing the central "home" position, two target regions (one to the left and one to the right of the home position), and a marker representing the current position of the participant's COP (see Figure 1). Participants were first given a short period of time (approx. 1 min) during which they could move their center of pressure (by shifting their weight) freely in order to familiarize themselves with the on-screen interface. Each trial during the Adaptation and Washout phases then involved maintaining COP in the center position for 3 seconds, moving their COP to the left or the right target, maintaining their position inside the target for 2s, and then moving back to the center base. In the Adaptation phase, participants executed 150 displacements of their COP toward the left or right target (randomized order, 50% of trials in each direction). Changes in the color of the selected target border (from red to green) indicated to which target participants had to move their COP. Following an initial 30 trials under normal feedback conditions, a bias was introduced in the display of the COP to the right for half of the participants and to the left for the other half. The bias was gradually increased over 60 displacements, reaching a maximum of 3 cm. At that point, the COP was located 3 cm to the left or right of the real position of the center of pressure. The full bias of 3 cm was then maintained for 60 displacements.

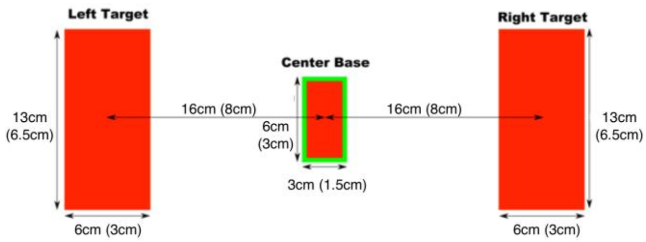

Figure 1. *Positions of the center base and the targets. The distances are presented in units of the on-screen visual representation and the corresponding COP displacement on the force plate (in brackets).*

For the No-feedback phase, the participants were asked to perform 10 COP displacements (5 movements in each direction) replicating the movements performed in the Adaptation phase while the center position, targets and representation of the participant's COP were not visible. Only an arrow indicating to which side participants had to move the COP was visible. This allowed us to determine whether the compensatory changes induced in the Adaptation condition were dependent on the presence of altered visual feedback. The Wash-out phase consisted of 30 trials under conditions identical to that of the Adaptation condition, but with the bias removed (normal visual feedback), at which point the participant unlearned the compensatory changes that took place during the Adaptation phase.

2.2 Data analyses

Force in two dimensions (mediolateral; anteroposterior) was sampled at 50 Hz and digitally low-pass filtered at 6 Hz using a second-order Butterworth filter (Matlab v. 7.0, Mathworks, Natick, MA) prior to the calculation of the COP along each axis (mediolateral and anteroposterior). For the quiet standing trials, COP measures were calculated over the final 50 seconds of the 60 second standing period. In the No-feedback phase, average COP was determined during the first 2s during which participants remained stable in the center area within an area delimited by a 4cm x 4cm square. The difference between the two groups of participants (right bias vs. left bias) was evaluated using independent-samples t-tests. Measures of COP *range* and *mean absolute velocity* along each of the two axes were also calculated during the 1-minute periods of quiet standing to evaluate the impact of the sensorimotor adaptation procedure on postural control. The range and mean velocity of COP have been shown in numerous studies to be reliable indicators of postural performance (Lafond et al, 2004; Raymakers et al, 2005). One-way repeated-measures ANOVAs were carried out separately for each dependent measure (COP range and velocity) and each axis (mediolateral and anteroposterior), comparing Baseline, Adaptation and Washout phases. Post-hoc comparisons were carried out as needed using repeated-measures t-tests with the Holm-Bonferroni correction for multiple comparisons.

3. RESULTS

Immediately following the Adaptation phase, participants in the left-bias group showed an average COP during quiet standing located 0.6 cm to the left of the reference position (Figure 2, left panel), while participants in the right-bias group showed a mean COP of 0.7 cm to the right of the reference position (Figure 2, left panel). This difference between groups in the mediolateral axis was statistically reliable (t(18)=0.0004). Following the Washout period, these biases were reduced to 0.008 cm and 0.2 cm for participants in the left- and right-bias groups respectively, and the difference was no longer statistically significant (p>0.05). No differences between groups were observed in the anteroposterior axis (p>0.05).

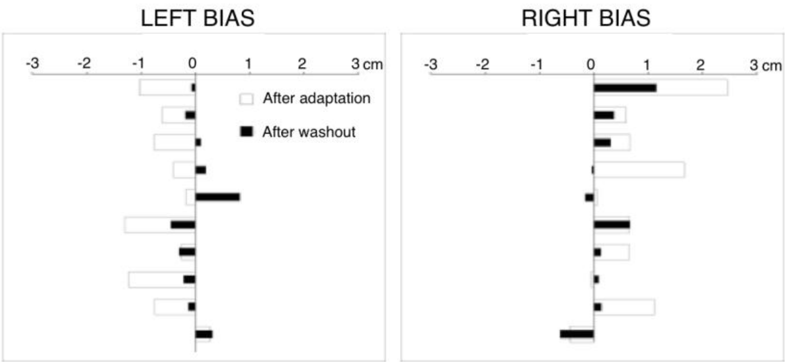

Figure 2. *The mean COP bias observed during 1-minute of quiet standing following the Adaptation and Washout phases for both groups (left and right bias).*

During the period of No-feedback following the Adaptation phase, the mean COP in the mediolateral axis was also found to be significantly different between the two groups (t(18) = 0.0004), corresponding to a 0.8 cm bias to the left of the reference value and 0.5 cm bias to the right for the left- and right-bias groups respectively. This indicates that changes in postural control induced by the altered visual feedback persisted beyond the immediate feedback manipulation. No difference was observed between groups along the anteroposterior axis (p>0.05) during the No-feedback phase.

In addition to the between-group differences in COP presented above, evidence for changes in postural control following the Adaptation phase comes from measures of COP *range* and *velocity* (Figure 3). Across participants in both groups, a reliable overall difference in COP range was observed between phases (baseline, following Adaptation, and following Wash-out) in the mediolateral direction (F[2,46]=9.4, p < 0.001), but not in the anteroposterior direction (p > 0.05). Similarly, a reliable overall difference was found between phases for the measure of COP velocity (F[2,46]=5.8, p < 0.01) in the mediolateral direction, but not in the anteroposterior direction (p > 0.05). Post-hoc tests revealed significantly larger values of COP range following the Adaptation (t[23]=3.99, p<0.01) and Washout phases (t[23]=3.75, p < 0.01) compared to baseline. Similarly, significantly larger values of COP velocity were observed following the Adaptation (t[23]=2.64, p<0.05) and Washout phases (t[23]=2.67, p < 0.05) compared to baseline.

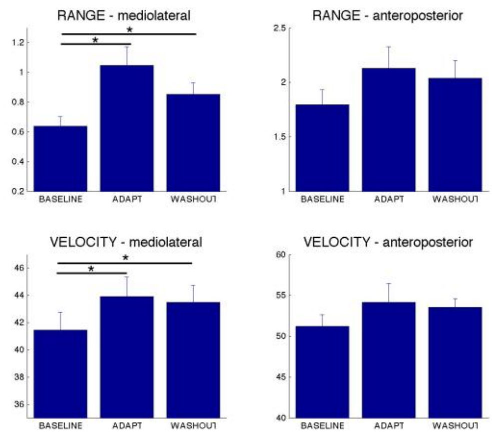

Figure 3. *COP range and velocity in the mediolateral and anteroposterior axes prior to the Adaptation phase (baseline), immediately following the Adaptation phase, and following the Washout phase.(* p< 0.05).*

4. DISCUSSION

The goal of the present study was to examine whether one could induce a short-term postural asymmetry in healthy participants by altering visual feedback during a dynamic postural control task. Following a period of practice under conditions of altered feedback, the COP position during postural quiet standing was found to be reliably shifted in the direction of the visual bias. This shift in COP was found to persist following the Adaptation phase when no visual feedback was present, indicating that the changes in postural motor control had in fact been learned by the participants. The induced postural asymmetry had an impact on postural control, as shown by larger COP range and velocity in the mediolateral axis.

Studies have shown that sensorimotor adaptation is a promising approach for the rehabilitation of upper limb motor control. For example, force-field adaptation during pointing movements has been used to improve the control of upper limb movements in children with primary dystonia (Casallato et al, 2012). Also, prismatic adaptation has been used to alter the attentional field in unilateral visual neglect patients (Jacquin-Courtois et al, 2013; Redding and Wallace, 2006, 2010). To our knowledge, the present study is the first to demonstrate that sensorimotor adaptation can be used to modify postural alignment. Children and adults with hemiplegia often exhibit asymmetric posture that could possibly be corrected using a sensorimotor adaptation procedure. Such clinical applications will be evaluated in future work testing procedures such as those used in the present study in populations with postural deficits.

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©2014 ICDVRAT; ISBN 978-0-7049-1546-6

Virtual anatomical interactivity: developing a future rehabilitation aid for survivors of Acquired Brain Injury

V Macri, P Zilber, V J Macri

3D PreMotorSkills Technology, LLC Durham, New Hampshire, USA

vjm@vincemacri.us

ABSTRACT

Anatomically realistic virtual upper extremities with analogous true range of motion were developed and made available in a platform of video game-like exercises and tasks to pilot test re-learning to plan and execute purposeful motor control and related executive function in survivors of acquired brain injury. The platform game-play is designed for survivors disabled from using physical extremities due to brain injury and for other conditions of brain-motor malfunction. Survivors control virtual upper extremities (before being able to control physical extremities), in order to simulate on-screen physical exercises and task completions, i.e. they stimulate brain processes for pre-action planning and training. This paper describes several imagery (visualization) methods of virtual reality rehabilitation, reports on use of a virtual anatomical interactivity ("VAI") platform by twelve participant/survivors of acquired brain injury and suggests opportunities for expanded collaborative research.

1. INTRODUCTION

Therapies and rehabilitation for survivors of acquired brain injury ("ABI"), including traumatic brain injury, stroke, focal dystonias and other brain-motor malfunctions address chronic disabilities of millions of individuals.

It is suggested that there is an on-going need to augment conventional physical and virtual reality therapies and rehabilitation by using pre-action planning and training simulations with cost-effective telemedicine delivery systems (http://www.ncbi.nlm.nih.gov/pubmed/18633000). Virtual Anatomical Interactivity (VAI) may have an adjunctive role as a simple, inexpensive (using any laptop, tablet, personal computer, hand-held device and the like) method to stimulate the brain to re-learn pre-action planning for upper extremity motor control and related executive functions for performing purposeful activities of daily living. Further research and development is warranted.

2. USE OF IMAGERY IN VIRTUAL REALITY THERAPIES/REHABILITATION

The innate human capacity to image (visualize) physical movements has been used in several methods of therapy/rehabilitation: motor imagery; action-observation therapy; and mirror therapy.

Motor imagery has been defined as an "internal simulation of movements involving one's own body in the absence of overt execution" (Butler and Page, 2006). Motor imagery, action observation and mirror therapy have been used for upper extremity motor improvement or recovery following ABI (Butler and Page, 2006) or to decrease or eliminate phantom limb pain following amputation (Ramachandran and Hirstein, 1998). Studies of these methods have reported stimulation of the supplementary motor cortex, premotor cortex, primary motor cortex, parieto-frontal circuitry, temporal gyrus, and ipsilateral anterior lobe of the cerebellum (Butler and Page, 2006; Ramachandran and Hirstein, 1998; Lacourse et al, 2004; Vromen et al, 2011). Mental imagery and practice have shown improvements in upper-limb movement for both range of motion (ROM) and strength, as well as reaching and grasp during functional tasks for individuals four weeks post-stroke (Ramachandran and Hirstein, 1998). Other studies using fMRI found that during mental imagery and practice, plasticity is upregulated in the hemisphere opposite to the lesion for participants with stroke (Lacourse et al, 2004, Hong et al, 2012).

Individuals unaffected by ABI who played commercial video games (e.g. Super Mario, Tetris) were reported to experience, as a result of that game-play, volumetric cortical increases (Kuhn et al, 2013; Haier, 2009). Wii™ and Kinect™ have been used in physical and occupational therapies to improve motor control for patients capable of moving affected extremities (http://www.wiihabilitation.co.uk/?cat=13). In contrast, VAI, called

PreMotor Exercise Games ("PEGs"), is directed to survivors who cannot move extremities and therefore need to re-learn planning to move. PEGs provide more than imaginary feedback in that control of virtual extremities to simulate physical movements and accomplish virtual tasks instantly results in viewable, on-screen actions representing instantiations of each survivor's personal imageries/visualizations. In PEGs game-play, each survivor imagines a desired physical movement, controls one or more virtual extremities to simulate purposeful movement, and views the simulated activity in the virtual world as though it were actual activity in the real world (i.e. creating one's own virtual movement for physical movement mirroring by the affected extremity).

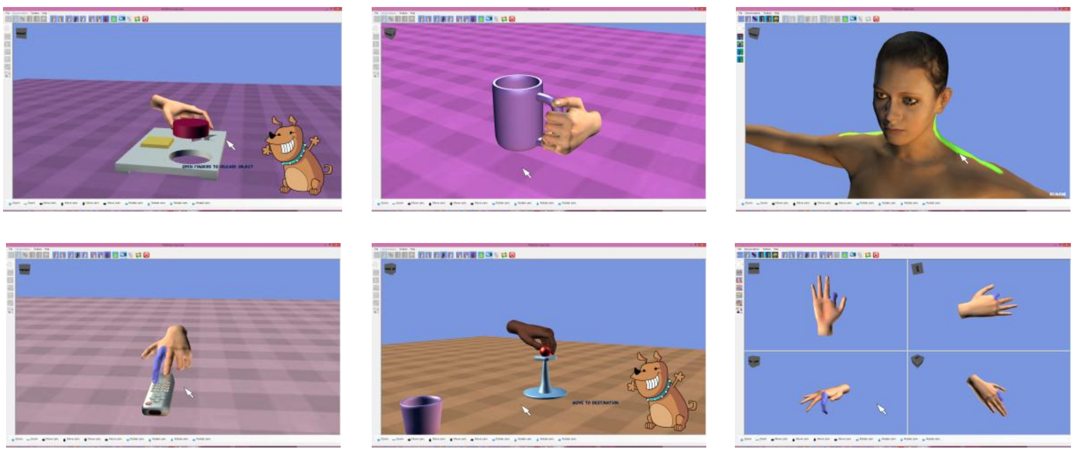
3. VAI PLATFORM USE BY TWELVE PARTICIPANT-SURVIVORS OF ABI

Twelve volunteer community program-based participant-survivors of ABI, in an institutional review board-approved study (report currently in press in a peer-reviewed journal), played only PEGs, no other video games (or physical or occupational therapy) during the study, averaging 20 minutes per session, three times each week for 20 weeks. Their average age was 53.9 years and the elapsed time post-injury was 11.4 years. Survivors' learning time for PEGs play averaged 5 minutes. Given that only volunteers participated, the few criteria included: being medically stable (examined by professional therapists supervising their daily activities); and presence of motor deficits determined by a Quick Functional Range ("QFR") and Strength Assessment. With an average elapsed time of 11.4 years post-injury, in some instances motor function disability remained unimproved post-intervention. Two baseline measurements were taken two weeks apart, before any PEGs intervention. Intervention outcome was a third measure. The tri-level measurement design was used to delineate intervention outcomes from participants' conditions at baselines one and two.

Virtual extremities are controlled by survivors' unaffected extremity or head movement via an input device, e.g. a standard computer mouse, touchscreen, or by webcam tracking head movements. Survivors point cursors to any or all parts of virtual fingers, hands, lower or upper arms, shoulders (right or left), and drag the part(s) to a new location and/or configuration. Survivors may execute virtual flexion/extension, supination/pronation, and abduction/adduction in any direction and at any angle. PEGs tasks for a virtual hand controlling virtual objects include: thumb and forefinger pincer movement to grasp a key; two finger movement to grasp a ball and drop it into a cup; multi-finger movement and action to pick up a spoon and drop it into a cup; full hand grasp around a mug handle; tapping movement and actions by index and middle fingers on a remote controller; and hand grasp of objects shaped as stars, circles, or squares then placement into correspondingly shaped slots. In addition, virtual movements may be directed by survivors to simulate real life tasks, such as: opening a designated correct box; with voice instructions to the survivor, selecting one box out of nine numbered boxes, screwing and unscrewing a light bulb, fitting pieces into a jigsaw puzzle, selecting numbers and executing arithmetic functions, and selecting letters to spell words. .

Measurements of motor skills improvements were made by: manual muscle testing using a goniometer to assess range of motion ("ROM"); a calibrated dynamometer to measure hand grip strength; and a pinch meter for testing strength for key, lateral and three-jaw chuck (tripod) grasps. Measurements of cognitive performance were made using the Executive Function Performance Test.

4. SELECTED SCREEN VIEWS



5. RESULTS

Chronic conditions of the participants were unchanged during the two week baseline period but improved, as noted below, after PEGs intervention. All results discussed below are post-intervention.

5.1 Shoulder Flexion/Strength

Shoulder flexion range of motion and strength were evaluated for nine participants, those having active shoulder movement. The normal range of motion for forward shoulder flexion is about 180°. For these participants, the mean ranges for improved shoulder movement were 99.9° to 126.3°, respectively. The nonparametric Friedman test for repeated measures ANOVA showed these differences to be statistically significant ($p = 0.02$). Participants no. 3 and no. 6 showed marked improvements ranging from trace to fair strength, while participants no. 8 and no. 11 showed improvements from fair to normal strength.

5.2 Wrist Flexion/Strength

The normal range of movement for wrist flexion is from about 60° to about 80°. Improvements were recorded in five participants, nos. 3, 6, 7, 10, and 11. For these five the range of movement improved from an average of 54° to an average of 67°. The difference was significant, as indicated by a nonparametric t-test ($p = 0.04$). Wrist strength remained generally stable for the participants, except for participant nos. 3, 6, and 8. These participants showed improvements in wrist strength from trace to poor, trace to fair, and good to normal, respectively.

5.3 Elbow Flexion/Strength

Elbow flexion range of movement and elbow strength were evaluated for the participants. The normal range of motion for elbow flexion is about 150°. Slight improvements were observed in participant no. 4 (5°), no. 11 (13°), and no. 12 (5°). The mean range of motion for these three participants increased slightly to 120.2°, 121.0°, and 131.5°, respectively. Participants no. 3, no. 6, and no. 8 showed improvements in elbow strength from trace to poor, trace to fair and good to normal, respectively.

5.4 Cognitive Skills

Cognitive skills of the participants were evaluated using the Executive Function Performance Test (“EFPT”) (Baum et al, 2008). The EFPT measures skills in initiation, organization, sequencing and safety. The EFPT tasks were cooking, taking medication, placing telephone calls, and paying bills. Activity demands of the EFPT included opening medicine bottles, reaching and using cooking tools, and using a calculator for paying bills. For overall EFPT task completion, ten participants performed at the level of complete independence following PEG intervention. The mean improvement in cognitive skills was statistically significant ($p = 0.02$). Nine participants demonstrated improvement in overall task performance. Improvement was noticeable in seven participants (nos. 1, 2, 3, 4, 6, 7, and 8). The mean difference on the global EFPT score was statistically significant ($p = 0.02$).

6. FUTURE STUDIES

Future VAI research questions related to survivors’ use of the VAI/PEGs platform include: 1) are cortical volumetric changes observed; 2) if so, which cortical areas are activated; 3) does manipulating virtual extremities activate different cortical areas than manipulating virtual extremities plus virtual objects to engage in virtual tasks; 4) how does 3), above, compare to cortical activity of unaffected individuals making actual physical movements or controlling virtual extremities; 5) compared to playing PEGs alone, do survivors’ motor recovery results differ if, in addition to controlling virtual affected extremities, survivors’ corresponding physical extremities are simultaneously stimulated by an applied device?

7. CONCLUSION

It is suggested that human imagery (visualization) and simulation (Ramachandran, 2011; Iacoboni, 1999) can be instantiated by survivors controlling virtual extremities to simulate physical movements and tasks and stimulate motor re-learning/planning. Survivors of ABI playing PEGs can instantly view feedback of such personally controlled movements and tasks. For re-learning planning for motor control and related executive function, PEGs should be further researched and developed in larger trials closer to the event of participants’ injuries as a future adjunctive therapy/rehabilitation.

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Enhancing brain activity by controlling virtual objects with the eye

C Modroño[1], J Plata[2], E Hernández[1], I Galván[1], S García[1], F Zelaya[3], F Marcano[1], O Casanova[1], G Navarrete[4], M Mas[1], J L González-Mora[1]

[1]Department of Physiology, University of La Laguna, Campus de Ciencias de la Salud, La Laguna, Tenerife, SPAIN

[2]Department of Neurosurgery, Hospital Universitario de Canarias, La Laguna, Tenerife, SPAIN

[3]Centre for Neuroimaging Sciences, King's College London, De Crespigny Park, London, UK

[4]Laboratory of Cognitive and Social Neuroscience, Diego Portales University, Vergara 275, Santiago, CHILE

cmodrono@ull.edu.es, jplata5@hotmail.com, estefaniahdezmartin22@gmail.com, ivan.galvan3@gmail.com, lmsofias1993@gmail.com, fernando.zelaya@kcl.ac.uk, fmarcano@ull.es, ocasanova@ull.es, gorkang@gmail.com, mmas@ull.es, jlgonzal@ull.es

[1]*www.ull.es,* [2]*www.gobiernodecanarias.org/sanidad/scs/huc,* [3]*www.kcl.ac.uk,* [4]*www.udp.cl*

ABSTRACT

Stimulation of the damaged neural networks is a key factor for the reorganization of neural functions in the treatment of motor deficits. This work explores, using functional MRI, a system to activate motor regions that does not require voluntary limb movements. Healthy participants, in a virtual environment, controlled a virtual paddle using only their eye movements, which was related with an increase of the activity in frontoparietal motor regions. This may be a promising way to enhance motor activity without resorting to limb movements that are not always possible in patients with motor deficits.

1. INTRODUCTION

Physical therapy is a common treatment for motor deficits but it is not always possible because of limitations in the affected limbs. Thus, alternative approaches have been used to support the recovery of motor functions by generating an activation of the sensorimotor system without resorting to overt voluntary movements (Szameitat, Shen, Conforto and Sterr, 2012). One approach is based on passive movements caused by an external agent. Another approach is based on motor imagery, i.e. the mental rehearsal of motor acts in the absence of actual movement production (Zimmermann-Schlatter, Schuster, Puhan, Siekierka and Steurer, 2008). There is a third approach (action observation therapy), based solely on the visual presentation of actions, which may facilitate the reorganization of the affected motor areas, and has demonstrated good therapeutic results (Carvalho et al, 2013).

Several basic imaging studies, outside the field of the neurorehabilitation, comparing different kinds of limb and eye movements have supported the idea that the cortical representations for diverse movements, specifically frontal and parietal circuits for limb and eye movements, are highly distributed and overlapping in the human brain (Filimon, 2010). This overlap, which may seem surprising at first, is not so surprising if one takes into account that limb and eye movements are naturally coupled in daily life (Levy, Schluppeck, Heeger and Glimcher, 2007). Thus, it would not be unreasonable to think that eye movements could be used in some way to generate brain activity related with limb movements.

Considering the results of such basic studies, this work explores a new system to activate sensorimotor regions in healthy participants that does not need voluntary limb movements. The idea is to use the eye (instead of the limb) to control objects in a virtual environment. Here, the object is a virtual paddle that is controlled by the participants in the context of a digital game. Participants in a functional MRI experiment move the virtual paddle to hit a ball using their eyes (with an eye tracking system) or just observe the game (baseline). An increase of frontoparietal activation might be expected when participants are using the eye as effector because of the overlapping of brain circuits for limb and eye movements. If this expectation is confirmed, it could have a potential application in the field of the virtual reality neurorehabilitation.

2. MATERIALS AND METHODS

2.1 Participants

15 right-handed neurologically healthy subjects (10 female, 5 male) between 19 and 21 years of age (mean=20.8; SD=0.6). They had normal or corrected-to-normal vision. The study was approved by the local Ethics Committee (University of La Laguna) and was conducted in accordance with the Declaration of Helsinki.

2.2 Virtual environment

A virtual 3D environment, using Visual C# and DirectX, was developed where the subjects play a paddle and ball game from an egocentric perspective. Participants had to prevent the ball entering the space behind them by trying to hit the approaching ball back towards the opponent (the computer), who controlled its own paddle (Figure 1). The paddle had one degree of freedom (left-right) and was cuboid in shape.

Participants used their gaze to control the virtual paddle. This was done by using an MRI-compatible eye tracking system (MReyetracking, Resonance Technology Company, Northridge, CA), which obtains the participant's gaze point in real-time. This system includes a Software Developer's Kit (SDK) that allows programs like the virtual game to interface with the eyetracker. The gaze point horizontal coordinates were transformed into positions of the virtual paddle using this SDK, which allowed the participant to control it in real-time.

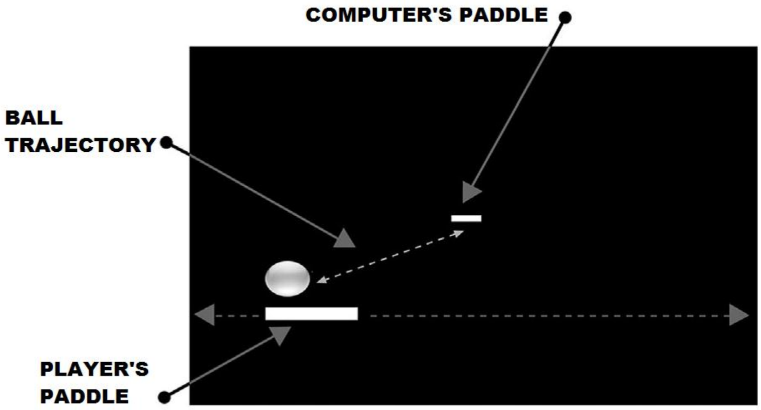

Figure 1. *The virtual game. Participants used their eyes to control a paddle to hit an approaching ball. The paddle had one degree of freedom (left-right). The display had a 3D feel, so the more distant computer's paddle was smaller and further away.*

2.3 Data acquisition

The fMRI run consisted of three conditions: *play*, *observation* and *fixation*. The *play* condition consisted of six 20 s blocks where the participant was playing against the computer using the gaze. During the *observation* condition, the participants just watched another six games. These observed games were similar to the executed games, but in this case the two paddles were controlled by the computer. The *play* and *observation* blocks were presented in random order and were preceded by a *fixation* task where the player stared at a grey cross in the middle of a black screen. The participants were instructed to focus on the game during the *observation* periods. Visual stimuli were given via MRI compatible eyeglasses (Visuastim, Resonance Technology, Northridge, CA).

Axially oriented functional images were obtained by a 3T Signa HD MR scanner (GE Healthcare, Milwaukee, WI) using an echo-planar-imaging gradient-echo sequence and an 8 channel head coil (TR = 2000 msec, TE = 22 msec, FA = 75º, matrix size = 64 x 64 pixels, 36 slices, 4 x 4 mm in plane resolution, spacing = 4 mm, ST = 3.3 mm, interleaved acquisition). The slices were aligned to the anterior commissure - posterior commissure line and covered the whole brain. High resolution sagittally oriented anatomical images were also collected for anatomical reference. A 3D fast spoiled-gradient-recalled pulse sequence was obtained (TR = 6 msec, TE = 1 msec, FA = 12º, matrix size= 256 x 256 pixels, .98 x .98 mm in plane resolution, spacing = 1 mm, ST = 1 mm).

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2.4 Data analysis

Data were preprocessed and analyzed using the software SPM8 (www.fil.ion.ucl.ac.uk/spm/). The images were spatially realigned, unwarped, normalized and smoothed using standard SPM8 procedures. The three conditions were modelled in the design matrix for each participant. Activation maps for the contrast *play > observation* were generated for each subject by applying t statistics. These first level contrast images were used in a random effects group analysis. Statistical maps were set at a voxel-level threshold of $p<0.05$, FDR corrected for multiple comparisons, and a minimum cluster size of 25 voxels.

3. RESULTS

Figure 2 shows the brain regions that were more activated when participants played the game using their gaze than when they were just observers. Many of the activations appear located in areas related with motor aspects (Kandel, 2013). It is worth mentioning here the extended, bilateral activity that was found in a region centred in the Brodmann area 6 (premotor cortex and supplementary motor area). Bilateral activity was also found in several regions of the inferior and superior parietal lobules (such as the supramarginal gyrus, the angular gyrus and the precuneus). The occipital lobe and the cerebellum were also bilaterally activated, and, to a lesser extent, some temporal areas.

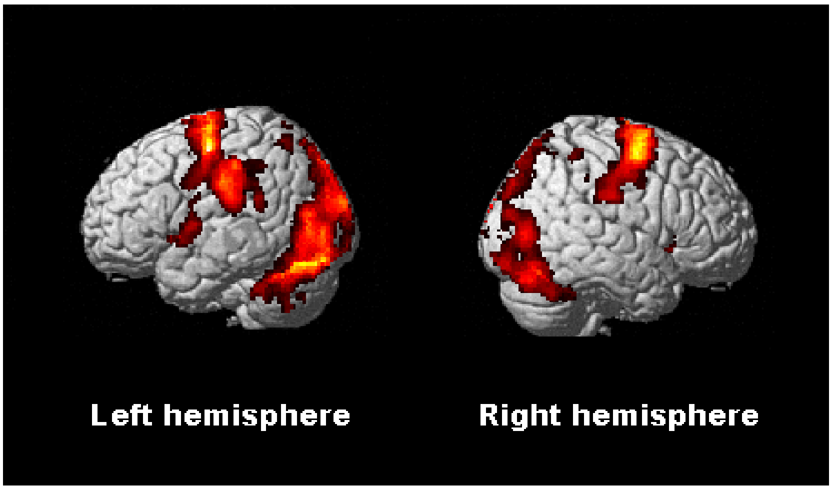

Figure 2. *Results of the play > observation contrast. When compared with an observation task (with a similar visual input), controlling the virtual paddle using eye movements was associated with an increase of the activity in frontoparietal motor regions (group analysis, N=15, threshold: $p<0.05$ at the voxel level, false discovery rate [FDR] corrected for multiple comparisons; minimum cluster size=25 voxels).*

4. CONCLUSIONS

In line with our expectations, when compared with an observation task with a similar visual input, using the gaze to control a virtual object is associated with an increase of the activity in frontoparietal motor regions. A key factor influencing reorganization of function in damaged neural networks is stimulation (Johnson-Frey, 2004), and the method presented here may be a promising approach to enhance motor activity without resorting to voluntary limb movements. Another advantage of this approach is that the control of a virtual object with the gaze may be more entertaining for the patients than other kinds of tasks used in rehabilitation, which therefore may help the patient to adhere to the therapy. In the future, attractive neurorehabilitation gaze-based systems could be developed for the users, which may be especially useful in the case of children and adolescents. Therefore, the results presented here can be of interest for researchers, developers and medical professionals working in the field of the neurorehabilitation.

Acknowledgements: We acknowledge the support of Servicio de Resonancia Magnética para Investigaciones Biomédicas de la Universidad de La Laguna and the following national competitive programs: Ministerio de Ciencia e Innovación [PTA2011-4995-I, TIN2011-28146]; Ministerio de Industria, Turismo y Comercio [TSI-020100-2011-189, TSI-020100-2010-346]; Ministerio de Economía y Competitividad [IPT-2012-0961-300000]. We also thank Miguel Angel León Ruedas for his assistance with data acquisition.

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Minimally invasive, maximally effective: multisensory meditation environments promote wellbeing

H J Moller[1–3], L Saynor, H Bal[2], K Sudan[3]

[1]Faculties of Medicine, Knowledge Media Design, Music and Health Research Collaboratory, University of Toronto, Toronto, Ontario, CANADA

[1]Faculty of Applied Health Sciences, Dept of Recreation and Leisure Studies University of Waterloo, Waterloo, Ontario, CANADA

[2]Digital Futures Initiative, OCAD University, Toronto, Ontario, CANADA

[3]Praxis Holistic Health, 785 Carlaw Ave, Suite 101, Toronto, Ontario, CANADA

drmoller@praxisholistic.ca, lsaynor@praxisholistic.ca, harjotbal@me.com, ksudan@praxisholistic.ca

www.utoronto.ca, www.uwaterloo.ca, www.ocadu.ca, www.praxisholistic.ca

ABSTRACT

Increasing evidence is pointing towards the health benefits of leisure: freely chosen, intrinsically motivated and self-directed "flow states", often environment-directed and quite probably with the potential to enact potent changes of consciousness. Optimal leisure experiences are thought to result in enhanced mental wellbeing, positive affect and transformational learning states that carry over into effectively coping with daily routines, stresses and roles. Our group has developed and researched the medically supervised administration of standardized simulated leisure-state meditation experiences in the context of pleasant, hedonic sensory input incorporating multiple sensory channels (visual, auditory, haptic) to promote broad-spectrum wellbeing in mental health care. In this brief report, we report on clinical outcomes for a case series of patients undertaking a therapeutic protocol of **TEMM**- a technology-enhanced multimodal meditation stress-reduction program with a broad-spectrum mental health benefit, analogous to conventional Mindfulness Based Stress Reduction (**MBSR**) programs, and a therapeutic risk-benefit margin possibly superior and often preferred by patients to medication therapy attending a holistic health centre. We touch upon seamless diagnostic evaluation and clinical utility of Wellpad, our Electronic Medical Record (**EMR**) system developed using an iterative Inclusive Design approach. We place our multisensory meditation therapy within the scope of Virtual Environment Therapy (**VET**) and suggest the mechanism of action as an induced leisure or flow state to potentiate relaxation, stress-reduction, resilience and personal transformation. The relevance of leisure states to wellbeing and specifically positive experiential learning through inspirational/motivational shifts in consciousness delivered via multimodal immersive environments are described as an important health promotion avenue to pursue and the VET research community to consider.

1. INTRODUCTION

It is fair to say that VET-based therapies have struggled to integrate into mainstream mental healthcare, yet the opportunity in the current era to demonstrate relevance in the healing arts is greater than ever. For some time, there has been promise that media technologies such as VET's could provide effective and standardized health delivery options (Gregg and Tarrier, 2007). Holistic healthcare paradigms incorporating media technology may now play a role in delivering on this promise. In an era where there is a crisis of confidence among the public and academia in scientific reporting of biomedical healthcare studies (Pashler and Wagenmakers, 2012), informed patients now often seek wellbeing restoration rather than illness treatment as a true healthcare goals (AMHA, 2003); given this trend, the opportunity has arisen for immersive technologies to clinically deliver longstanding health claims of representing a pathway towards credible, safe and effective therapeutics. Many patients skeptical of biomedical risk-benefit ratios gravitate to holistic and/or "natural" health and wellness models, such as meditation, yoga, naturopathy, or massage therapy (to name a few). Particularly in mental health care, conventional therapeutic options are often ineffective and/or limited by undesirable iatrogenic side effects, leading to non-compliance. Ideal VET's that seek to improve upon this track record of biomedical therapies need to be salient, aesthetically pleasing and hedonically rewarding, causing patients to seek them out, rather than enduring them through cumbersome tasks or aversive stimuli such as typical VET phobia protocols.

At our health centre, reproducible technology-enhanced multimodal meditation (TEMM) protocols are gradually being developed into therapeutic programs to meet the needs of patients seeking mental health care for safe and effective symptom relief of stress-related symptoms such as anxiety, insomnia and depression. As boundaries between real and virtual, technologically mediated and "organic" states of consciousness continue to blur with the march of media technology, the need to address this convergence in a therapeutic paradigm is increasingly relevant and warranted (Moller, 2008). In parallel to this, the fast pace of technology in work environments, and the impact of this on health is being described (Heusser, 2013). We have recently advocated for the public health implementation of more accessible leisure opportunities (Moller et. al 2014) to create a healthier and productive society via personalized immersive and standardized media-based therapeutics.

2. IMMERSIVE MEDITATION THERAPEUTICS DESCRIPTION

Our group has developed and researched the medically supervised administration of synthetically "packaged" leisure-state meditation experiences in the context of pleasant, relaxing hedonic sensory input incorporating multiple sensory channels (visual, auditory, haptic). Detailed psychobiological models have been previously reported (Moller and Barbera, 2006, Moller and Bal, 2013, Moller et al, 2014). As outlined above, the overarching goal of our meditation protocols is to simulate or "recreate" leisure states as per Mihaly Csikszentmihalyi's description of *"flow"* as an immersive, often hedonic state of absorption and peak performance with positive psychological outcomes (Csikszentmihalyi and Kleiber, 1990). Also described as "inner presence", (Revonsuo, 2006), this complex consciousness process involves the processing of sensory stimuli and consolidation with previously integrated information, very similar to that described in our neurobiological process of dreaming (Moller and Barbera, 2006), and in Csikszentmihalyi's *flow* model of highly memorable and meaningful peak states, using immersive simulated environments to approximate the best experiences of people's lives.

We now review briefly the clinical protocol for medical patients who have undertaken a standardized course of regularly scheduled (weekly or biweekly) medically supervised 20-40 minute multisensory technology-enhanced multimodal meditation (TEMM) sessions to therapeutically address stress-related symptoms in a psychosupportive paradigm. TEMM's multimodal nature consists of visual, auditory and haptic sensory cues to users. Visual cues in our current TEMM model are recurrent light pulses via specialized glasses using built-in light emitting diodes (LED's), at a frequency between 2 and 12 Hz, corresponding to the electroencephalographic (EEG) rhythm ranging from delta (1-4Hz), through theta (4-8 Hz) and alpha (8-12 Hz) brain activity, to entrain a calming and relaxed user state, compared to higher frequencies common in chronic high stress-states. The audio component typically involves exposure to a standardized guided meditation invoking a relaxing scenario such as a nature experience (e.g. walking in a meadow or sitting on a beach) accompanied by repetitive positive affirmations and mantras to enhance a participant's self-esteem or psychological outlook. Themes addressed within the meditation sessions include "dealing with stress", "relax", "balancing your moods" and "creative problem solving". The intent of the standardized audio content of the immersive TEMM-based meditation scenarios is to mimic, and on a therapeutic level, reprogram autonomous thought processes. Haptic sensory stimulation (gentle massage, heat, vibration) occurs through a specialized chair that the patient rests upon during the meditation process. Multimodal visual, auditory and haptic elements are synergistically combined within a therapy session to created an integrative and transformative therapeutic experience (see Figure 1). Pre- and post-treatment core psychosomatic self-states are assessed to track response.

3. CLINICAL PROGRAM REVIEW

3.1 Clinical Study

In our recently reported clinical study of 20 consecutive fully consenting patients seeking medical meditation in a holistic healthcare centre setting using the above protocol (Moller and Bal, 2013), participants were invited to complete a feedback form in which they were asked to describe the following: (i) Initial symptoms/ concerns which led to treatment (ii) Overall impression of the treatment (iii) Using 5-point Likert scales patients were asked to rate the following: (i) Effectiveness of the TEMM treatment for initial symptoms or concerns (ii) Adequacy of the duration of sessions (iii) Adequacy of the number of sessions. Another set of 5-point Likert scales were also used to allow patients to rate symptom-based self-states **before** and **after** the treatment plan, including the following: (i) Tension/Relaxation level (ii) Stress level (iii) Mood state. Lastly, patients were invited to provide open-ended qualitative feedback regarding additional observations comments. On average there was a noticeable decline in perceived levels of tension ($p < 0.001$) and stress ($p < 0.001$), before versus after the program, reported by study subjects. Over 50% of individuals specifically commented on the capacity for TEMM to help them relax and better deal with their stress and anxiety. For changes in mood states of patients there was a similarly positive shift (p = 0.019); the TEMM therapy program was found to be significantly effective in addressing the symptoms and concerns of subjects, with a mean rating of 4.15 points on the 5-point Likert scale. The layout of the treatment was favorably evaluated, with mean ratings for both individual session and program duration near the "neutral" 3 points on the 5-point Likert scale, i.e. close to the "just right" point. Some individuals also articulated their appreciation of the design of the TEMM program; using different sensory and psychological elements integratively seems to create a complete and powerful wellbeing experience. TEMM was consistently reported to have helped initiate an introspective dialogue for a select number of users—these individuals reported more self-awareness of emotions and anxieties and are better able to cope with them outside of the sessions, implying an experiential shift in consciousness. We have dubbed this transformative clinical outcome as a "vacation effect". Flow-related engagement with the therapy experience across multiple senses was described by many patients as engendering a holistic therapeutic benefit, despite some variation in awareness and recollection of the specifics of the guided meditation they had experienced. This is reminiscent of the residual leisure experience of a vacationer returning from a journey or trip and being able to remember and integrate novel thought patterns and/or behaviours observed and experienced into their daily routine.

3.2 Ongoing Diagnostics Program

A helpful approach to reliably track patient progress is to make this process easy and even enjoyable for patient and provider. In this sense, to complete a holistic immersive therapeutic experience, the gathering of clinical data should ideally be non-obtrusive and facilitate patient-doctor communication across a wide clinical population base. Our tablet-based Wellpad electronic medical record (EMR, see Figure 2) tool represents our team's commitment to Inclusive Design principles (Nussbaumer, 2001, Marti, 2012) in gathering quantitative and qualitative results by establishing *"a universal language that bridges the gap between patient and doctor/circles-of-care, while accommodating the growing reality of diversity in a global community with common health concerns but often differing language and culture."* (Moller and Saynor 2014). Patients of varying cultures, cognitive and physical abilities find self-reporting using Wellpad's novel Happy- and Frowny-face sliders to be a significant improvement over complex and confusing paper-based questionnaires, and also report that Wellpad's easy-to-understand data visualization display is helpful to summarize their clinical progress during appointments.

3.3 Ongoing therapeutics development

A related immersive meditation-based therapy that shows promise for our patient group is vibroacoustic therapy (VAT). Conceptually similar to TEMM, VAT utilizes transducers (loudspeakers), positioned throughout a bed, providing somatic/haptic stimulation with low frequency sound waves, (usually at 40 Hz or less). While the body is subjected to these low frequency waves, patients are also immersed in binaural auditory music programs delivered via headphones, with pulsating soundscapes comprised of calm and relaxing music. This induces a pleasant wellbeing state for patients, while alleviate pain or reduces nociception (Wigram and Saperston, 2013, Naghdi et al, 2014). Operationalization and optimization are still core areas of focus for this immersive therapy, but it shows much promise in the further design of multisensory meditative therapies facilitating stress, pain and tension reduction.

4. CONCLUSIONS

We have described a theoretical framework, rationale and early user feedback for standardized therapeutic VET leisure-experiences packaged as immersive media-based meditation programs. We wish to point out the potential societal benefit of health promotion on a preventative level through TEMM therapy, for example, if more closely linked to workplace health management services. Specifically with difficulty in regularly scheduling predictable vacations or other leisure events, the notion of "bringing leisure into the workplace" may be a promising avenue to pursue for employee wellbeing and productivity. The acute as well as residual effects of such simulated leisure states appears able to approximate real experiences, and perhaps even deliver these more efficiently and predictably. While similar outcomes might ordinarily occur with conventional leisure activities such as play, enjoyment of outdoor nature experiences or cultural activities, it is intriguing to consider that immersive media technologies might be able to operationalize these experiences in a standardized format, allowing essentially a supervised "prescription" of leisure-based multimodal meditation experiences by healthcare professionals trained in this paradigm. This could have significant health policy implications as well as reinventing service delivery in workplace wellbeing initiatives (e.g. Peters et al, 2013). Clarifying differences between individuals and linking qualitative "lived experience" reports to clinical data would be a welcome next step. The possibilities of personalized experience design of immersive wellbeing environments appear wide open for future work, discovery and implementation.

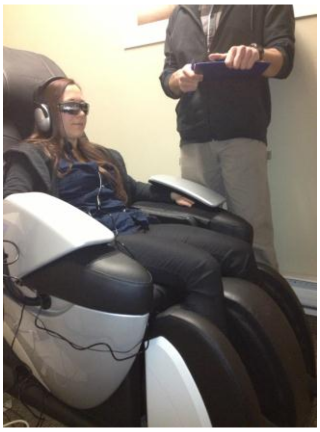

Figure 1. *Medically supervised TEMM therapy.*

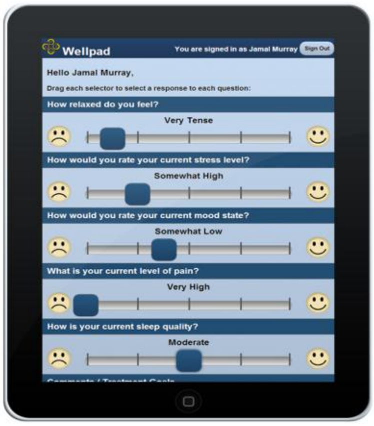

Figure 2: *Wellpad EMR Symptom Tracking Tool.*

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Raised-dot slippage perception on fingerpad using active wheel device

Y Nomura, H Kato

Department of Mechanical Engineering, Mie University, Kurimamachiyacho, Tsu, JAPAN

nomura @mach.mie-u.ac.jp, www.int.mach.mie-u.ac.jp

ABSTRACT

To improve the slippage perceptual characteristics with the fingertip cutaneous sensation, we have introduced raised dots on the surface of a wheel rotating on an index fingerpad. Examining the perceptual characteristics of the raised-dot slippages by psychophysical experiments, we obtained factor effects on the perception. As a result of ANOVA, it was confirmed there was a significant difference among the three surfaces: the 3.2 mm period of raised dots, the 12.8 mm periods of raised dots, and the without-raised-dots smooth surface.

1. INTRODUCTION

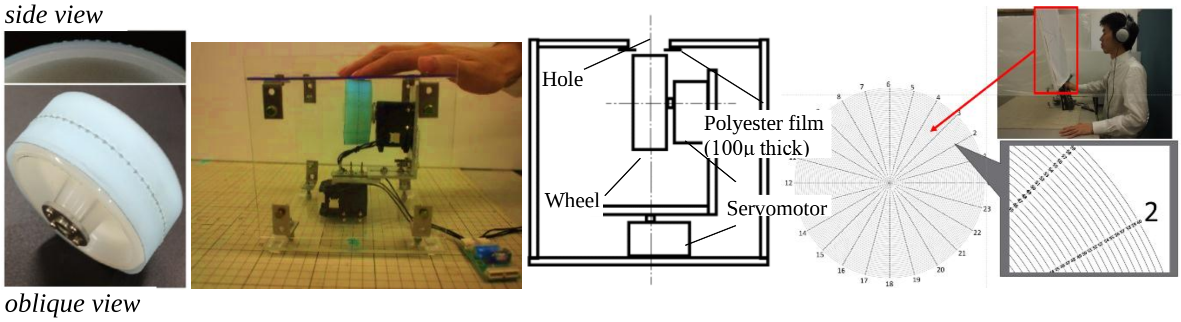
A prototype of the slippage-displaying device that embodied a wheel rotating on an index fingerpad was studied in this paper. Perceiving velocities for some periods, subjects can continuously move their hand: integrating the motions, they can further perceive line drawings such as the multi-stroke characters. It would be helpful for visually impaired persons. To improve the slippage perceptual characteristics via cutaneous sensation, we have introduced raised dots on the sliding surfaces of the wheel. The raised dots give subjects distinct stimuli of concave deformations moving on the fingerpad skin surface the distinctiveness is expected to enhance the slippage perceptual characteristics. As for the use of the raised dot, Dépeault et al. (2008) studied perceptual characteristics with raised-dot sliding-speed scaling. Sarada et al. (2004) also reported some characteristics with slip velocities and directions: together with a sandblasted homogeneous rough surfaces, they employed a specific dot surface made of small circular bulging edges: the Weber fraction with the slip-speed perception was improved from 0.25 to 0.04, and the difference thresholds between slip-directions were also improved from 11.7 to 3.6 degrees. Taking notice of not only the velocity, but also the perceptual time period, the authors extend perceptual tasks from the velocity to the length (Nomura et al, 2013): a speed perception scheme worked for the high-speed condition or the multiple dot contact condition, while a dot counting scheme did for the low-speed and single dot contact condition. The mechanical configuration was extended from the linear actuator-based translation to servomotor-based rotation towards mouse type tactile devices in this work.

As with the mouse type fingertip tactile devices, Kyung et al. (2004) proposed a multi-functional mouse providing 1-D grabbing force as well as 2-D translation force, together with pin array tactile patterns. Gleeso et al. (2010) proposed a device providing a 2-D tangential skin displacement. Tsagarakis et al. (2005) used a V-configuration of frustum cones to provide the 2-D tangential slip/stretch as the velocity vector by the form of producing a vector sum: the discrimination angle was 15 degrees with about 70 % correct answer rate. Webster et al. (2005) produced the sliding contact through the rotation of a ball: values relating to just noticeable differences (JNDs) with directional differences were given as 20–25°. Contrasting to these being forced to use non-bumpy surface, the authors introduced raised dots to enhance the slippage perceptual performance in this work.

2. EXPERIMENTAL METHOD

2.1 *Experimental Equipment*

Two kinds of bumpy films were introduced together with a non-bumpy film to clarify the advantages of the raised dots: (1) the surface with the dot interval of 3.2 mm as in Fig. 1 (a) (referred as “3.2mm-dot surface”), (2) the other one with the dot interval of 12.8 mm (referred as “12.8mm-dot surface”), and (3) the non-bumpy flat surface (referred as “flat surface”). Considering Japanese Standard with raised dots for tactile graphics, the raised dot size were 1.5 mm in diameter, and 0.4 mm in height. In addition, All the three films were made of a lapping film (#2000, grain size of 9μm, 3M Corp.) to make the experimental results general. The films were adhered to the cylindrical surface of a wheel. The wheel was 65 mm in diameter, and was able to be rotated with respect to orthogonal two axes by a couple of servomotors. One servomotor was connected to the other base-fixed servomotor via a swivel joint. This mechanism made the wheel possible to rotate in 2-DOF (see Fig. 1 (b), (c)).



(a) Raised dots-formed wheel (b) Photograph (c) Schematic drawing (d) Answer board

Figure 1. *Experimental device.*

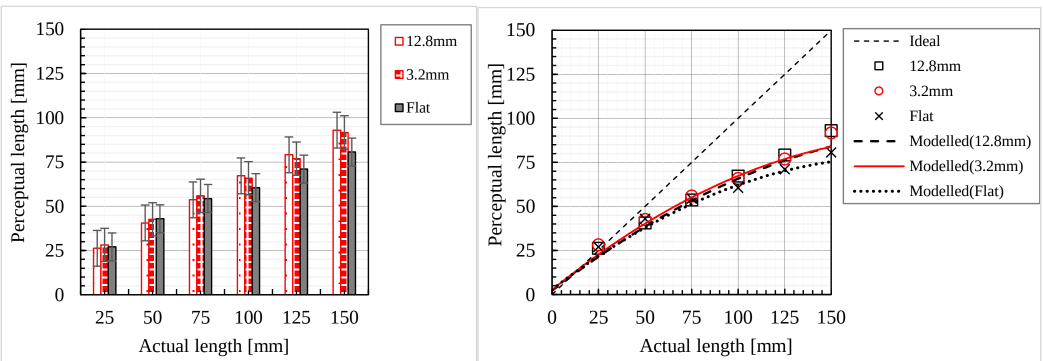
2.2 *Experimental Procedure*

Six right-handed male subjects aged 22 to 59 years, voluntarily participated in the experiment. Twisting neither their body at the waist nor their head at the neck, subjects were seated on a chair, and faced his front (see Fig.1 (d)). Setting their elbow flexion angle at about 90°, their forearm was set parallel to the table base, and was also set parallel to the direction in the sagittal plane. A white noise sound was applied to the subjects via headphones for avoiding any side effects on the slippage perception. Subjects touching the wheel surface on their fingerpad through a hole (12.8 mm diameter) of a polyester film (100µ thick), and the wheel was activated in arbitrary waiting times: it was swivelled to a direction, and was rotated by a specific angle where the servomotors drove the wheel in rectangular velocity patterns. The presented line lengths were 25, 50, 75, 100, 125, and 150 mm. The line directions were 0° (right) to 330° with the interval of 30° in the counterclockwise direction. The speed was set at 60 mm/s that is considered to be natural in ordinary active touches. The 8 lengths and the 12 directions made combinations of 64 line segment patterns, and they were ordered in a pseudo random way, and were presented twice for each of the three surfaces. Consequently, the total number of 432 (6×12×2×3) runs of line segment presenting experiment was carried out for each subject. The experiment took about 2 hours per subject. During experiments, the subjects were instructed to relax, and to focus on perceiving the presented linear sliding lengths via their index fingerpad. They were asked to answer the perceived lengths and directions by the following way. Just after the wheel stopped, they opened their eyes, looked at the answer board (see Fig. 1 (d)), and phonated a code number that represents the length and the direction.

3. EXPERIMENTAL RESULTS WITH THE PERCEIVED SLIPPAGES

3.1 *Experimental Results*

The relationships between the perceptual and actual lengths are shown in Fig.2 for each of the three surfaces: (1) 3.2mm-dot, (2) 12.8mm-dot, and (3) flat. Although a length-related nonlinearity occurred for all the three surfaces, the nonlinearity in both the dot surfaces was seemed to be much smaller than that in the non-bumpy surface.



(a) Column bar; mean. Error bar; standard deviation. (b) Symbol; mean. Line; modelled.

Figure 2. *Perceptual length characteristics for the 12.8mm-dot, 3.2 mm-dot, and flat surfaces*

Proc. 10th Intl Conf. Disability, Virtual Reality & Associated Technologies
Gothenburg, Sweden, 2–4 Sept. 2014
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The relationships between the perceptual angle errors and the actual angles are shown in Fig.3 for each of the three surfaces. There can be seen a trigonometric function patterns with approximately the same amount of biases of several degrees in the counterclockwise direction.

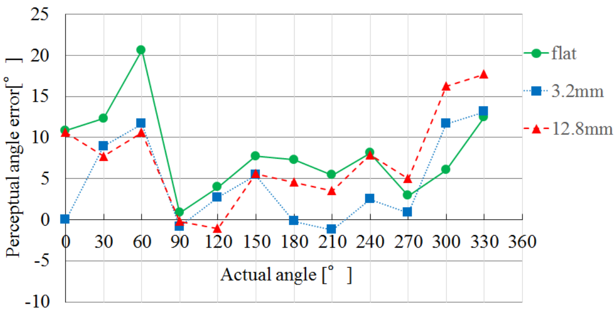

Figure 3. *Mean deviation of the perceptual direction for the three surfaces wrt the directions*

3.2 Discussion on Perceptual lengths

After applying a curve fitting to the above explained data, a statistical test, ANOVA, was applied. That is, a model value l_{model} of the perceived length l_{perc} was assumed to be given by a power function with the actual length L as in

$$l_{model} = \alpha \ L^{\beta} \tag{1}$$

The length-related nonlinearity can be expressed by parameters β: the less than 1 the value of β is, the larger the nonlinearity effect is. After taking logarithms of Eq. (1) as in

$$\ln l_{model} = \ln\alpha + \beta \ln L, \tag{2}$$

a linear least squares method was applied to the data for each combinations of the 3 surfaces, 12 directions, 6 subjects and 2 iterations. Then, the 432 pieces of the coefficient pair of ln α and β were estimated. Averages of the estimated ln α and β for each of the three surfaces were shown in Fig. 2 together with the modelled values.

Next, ANOVA test was applied to the estimated coefficients (see Table 1 (a), (b)). It can be concluded that there were significant differences among the three surface levels for each of the coefficients of ln α and β with the significant level of 0.01%, and that the 12.8mm dot showed a bit better performance than the others. While there was no significant difference with respect to the direction factor and the interaction factor.

ANOVA was also applied to the perceived angle errors as in Fig.3. We can conclude from Table1 (c) that there were significant differences of a 0.1 % level among the three surface levels and that the 3.2 mm dot showed much better performance than the others from the viewpoints of both the mean error and the random error (standard deviation). Although there were also significant differences with respect to the direction factor and the interaction factor besides the surface factor, the direction factor effect was the largest among them.

4. CONCLUSIONS

Introducing raised-dots for enhancing slide-length perceptual characteristics, the authors made a prototype of wheel-type slippage presentation device which was able to display velocity vectors via tactile sensation on human fingerpad. By integrating the perceic\ved velocities over duration times, line segments can be perceived. Al thiough the sample size was not enough to conclude definitely, and further examinations are necessary, the followings were tentatively obtained as a pilot study.

1. Based on the Steven's power law, the perceived lengths were modelled.
2. Perception of length: the 12.8 mm dot surface showed a bit better performance than the other 3.2 mm dot and flat surfaces.
3. Perception of angle the 3.2 mm dot surface showed much better performance than the other 12.8 mm dot and flat surfaces.

The experimental equipment used in this study was not enough compact to make use of mouse-interface, further development of miniaturization would also be needed in the future studies. In addition, since the experiments were conducted by sighted persons, the results should be applied to acquired blindness, and further studies shall be necessary for congenital blindnesses.

In the future the authors will embed the much smaller size of the wheel into a mouse as an active wheel mouse.

Table 1. *ANOVA tables*

(a) ln α (α, proportional coefficient wrt perceived lengths)

Factor	Level	Mean	Factor effect	Stand. dev.	DOF	Test stats. F-value	Dicision
Surface	12.8mm	0.94	-0.18	0.76			
	3.2mm	1.16	0.03	0.96			
	Flat	1.28	0.15	0.86			
					2	4.1	*
Direction					11	0.79	NS
Interaction					22	0.49	NS
Error				1.01	396		
Global		1.12		1.11	431		

(b) β (exponential coefficient wrt perceived lengths)

Factor	Level	Mean	Factor	Stand.	DOF	Test	Dicision
Surface	12.8mm	0.7	0.044	0.18			
	3.2mm	0.657	0.001	0.21			
	Flat	0.612	0.044	0.17			
					2	4.68	**
Direction					11	1.14	NS
Interaction					22	0.76	NS
Error				0.19	396		
Global		0.656		0.21	431		

(c) Perceived directional errors

Factor	Level	Mean	Factor effect	Stand. dev.	DOF	Test stats. F-value	Dicision
	12.8mm	7.36	0.53	16.05			
Surface	3.2mm	5.12	−1.71	13.28			
	Flat	8.00	1.17	20.52			
					2	7.75	***
Length					5	0.18	NS
	0°	9.44	2.62	16.7			
	30°	9.65	2.82	18.29			
	60°	13.47	6.64	16.3			
	90°	-0.07	-6.9	12.4			
	120°	1.88	-4.95	19.4			
Direction	150°	6.25	-0.58	18.37			
	180°	3.89	-2.94	13.63			
	210°	2.57	-4.26	17.56			
	240°	6.18	-0.65	16.57			
	270°	2.92	-3.91	10.72			
	300°	11.32	4.49	16.68			
	330°	14.44	7.62	16.99			
					11	19.39	***
Interaction					10	1.93	***
Error				15.98	2579		
Global		6.9		16.92	2591		

* P<0.05, ** P<0.01, *** P<0.001

Acknowledgements: This work was supported by KAKENHI (Grant-in-Aid for Challenging Exploratory Research 25560112 from Japan Society for the Promotion of Science (JSPS)

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Low-cost active video game console development for dynamic postural control training

A Pouliot-Laforte[1], E Auvinet[2], M Lemay[1], L Ballaz[1]

[1]Department of Kinanthropology, Université du Québec à Montréal,
141 av. President-Kennedy, Montreal, CANADA

[1,2]UHC Sainte-Justine Research Center,
3175 ch. Côte-Sainte-Catherine, Montreal, CANADA

[2]Departement of Mechanical Engineering, École Polytechnique de Montréal,
2900 boul. Édouard-Montpetit, Montreal, CANADA

[1]Quebec Rehabilitation Research Network, Montreal, CANADA

pouliot.annie@gmail.com, edouard.auvinet@gmail.com, lemay.martin@uqam.ca, ballaz.laurent@gmail.com

ABSTRACT

Weight shifting is a key ability to train and monitor in rehabilitation processes. In the last decade, active video game console (AVGC) has been viewed as a promising and appealing way to solicitate weight shifting ability. However, to date, no commercially available AVGC was specifically developed for balance and postural control throughout rehabilitation processes. The present study aims to establish a proof of concept about the possibility to integrate, in a unique AVGC, a board, monitoring the player centre of pressure and a Kinect, which take into account the postural movement and the player motor function capacity.

1. INTRODUCTION

Dynamic balance is particularly relevant in rehabilitation because of its importance in daily life activities (Brouwer et al, 1998). The ability to initiate and control weight shifts have been reported as a prerequisite for independent walking in various populations with motor disability (Eng and Chu, 2002). Performing weight shifting in response to a visual stimulus is a key ability to train and monitor in many motor impaired individuals (Dault et al, 2003; Laufer et al, 2000). More specifically, visually guided weight shifting is often required in everyday life situations. However, most tests currently used by clinicians and researchers involve self-generated weight shifting in which a person is asked to shift his or her weight within his or her stability limits (de Haart et al, 2005) and does not require responding to a visual stimulus.

The lack of evidence concerning visually guided weight shifting ability could be related to the difficulty to adequately evaluate and train this complex ability. Active video game consoles (AVGC) have been used in people with motor impairment to solicit M/L weight shifting in the context of visually guided and task-oriented movements (Snider et al, 2010). AVGC based on centre of pressure (CoP) displacement measurement could therefore be viewed as a promising and appealing way to induce such movements. Ballaz et al. (2014), evaluated the postural movement during a Nintendo Wii™ game (Nintendo, Kyoto, Japan) in children with cerebral palsy. They reported inappropriate trunk movements when participants with cerebral palsy shifted their weight from one leg to the other. This result highlighted the limit of this game controller, based on CoP displacement, to solicit adequate M/L weight shifting. Indeed, it is known that optimal weight shifting should be mainly performed with minimal trunk inclination (Michalski et al, 2012). Therefore, a video based controller should be added to take into account postural movements of the participants. Also, base of support width affects weight shifting and can vary greatly between participants, especially in a rehabilitation context. It is therefore crucial to consider this parameter to make sure that game requirements are adapted to the participant's weight shifting capacity.

In the next few years, we intend to develop and validate an AVGC dedicated to dynamic postural control rehabilitation. A first version of the AVG is proposed. The aim of the present study is to establish a proof of concept using different low-cost technologies to develop an innovative AVGC, which take into account the player weight transfer performance and the player postural movement. More specifically, this present study provides preliminary results on 1) trunk inclination and 2) base of support width measured using a video controller.

2. METHODS

An AVGC was developed combining the Nintendo Wii Fit board (Nintendo, USA) and the Kinect (Microsoft, Redmond, Washington, USA), to solicit M/L weight shifting in response to visual stimuli in a functional context. The association of the Wii Fit board and the Kinect allows quantifying both the CoP displacement (Bartlett et al, 2014) and the postural strategy (Clark et al, 2012) used by the player. The goal of the game is to catch water drops with a bowl that the player controls by moving laterally his CoP (i.e. performing M/L weight shifting). The Kinect provides the opportunity: (1) to quantify the weight shifting strategy used by the player and (2) to provide a visual feedback about the adopted posture. More specifically, when the player shifts his weight with an excessive lateral trunk bending, the bowl topples (see Figure 1). Based on previous work (Ballaz et al, 2014) the trunk inclination required to make the bowl topple was set at a 20° angle. The amplitude of weight shifting and the velocity of the water drops are adjustable depending on the functional level of the player.

Figure 1. *The visual feedback of trunk movement in the developed active video game.*

2.1 Participants

A convenience sample of 4 healthy adults aged between 24 and 38 years old (2 males and 2 females; mean age [SD]: 30.5 [6.8] years; body mass: 65.3 [14.0] kg; height: 175 [9] cm) were recruited from our research center. A child of 6 years old with cerebral palsy (CP) was also recruited to test the AVGC (Gross Motor Function Classification System level I; body mass: 24 kg; height: 117.3 cm).

2.2 Procedure

2.2.1 Evaluation of the Kinect system. Healthy participants were asked to stand on the Wii Fit board at a distance of 2.7 meter from the Kinect. They were asked to place their feet following verbal instructions given by the examiner and to keep the same feet placement during a 5 seconds period. Participants were asked to simultaneously place their right and left foot as follow: left side, middle and right side. By combining the left and right foot positions, a total of 9 positions were tested. Thereafter, the participants were asked to shift their weight by bending the trunk laterally. They had to complete a set of 10 weight shifting at different amplitude, i.e. small, medium and maximal amplitude. This procedure was implemented to report the parameters using the usual game configuration.

2.2.2 Evaluation of the AVGC. A child with CP was asked to play the game as described above, namely “Choplo”, during 5 minutes. The game parameters were defined as follow: Maximal tolerated trunk inclination: 20 degrees; water drop fall frequency: 0.3 Hz; maximal horizontally water drop distance, 20 cm (relate to the ankle distance). Here, we wanted to test the performance of this integrated multi-sensors system. No measurement was performed with this participant.

2.3 Measurements

For all tests, the data were recorded synchronously by the Kinect and a 12-camera motion analysis system (ViconMX, Oxford Metrics, Oxford, UK) cadenced at 100 Hz. Reflective markers, placed over several anatomic landmarks according to a slightly modified full body plug-in gait kinematic model, were tracked (see Ballaz et al, 2014 for details). Kinematic data were exported from the Vicon workstation software and subsequently analysed using MatLab 7.4 (The MathWorks Inc., USA). The Kinect data were recorded and analysed with Microsoft NUI library (Microsoft, Redmond, USA). Microsoft’s ‘Kinect for Windows SDK’, was used to provide an Application Programmer’s Interface (API) to the Kinect hardware. The API was used to interface with the Kinect sensor and its skeletal tracking software providing an estimate for the position of 20 anatomical landmarks at a frequency of 30 Hz. To characterize the trunk inclination during M/L weight shifting, the trunk was modeled as a one-segment rigid linked system. The trunk segment was defined by the C7 marker and the middle of the posterior pelvic markers. With the Kinect, the trunk inclination was defined as the angle between the spine and the shoulder center markers (as defined by the Kinect kinematic model) versus the world vertical axis. To quantify the foot position and thereby the base support width, the ankle joint centre position was estimated by averaging the position of the internal and external malleolus Vicon markers. The ankle distance measured by the Kinect was calculated based on the ankle joint center marker.

2.4 Statistics

Pearson correlation coefficients were calculated to quantify the relationship between the Kinect and the motion analysis measurement for the distance between the ankle and the trunk inclination angle. Individual correlation was assessed for the two variables on all four participants.

3. RESULTS

The trunk inclination angle measured with Kinect and the motion analysis system highly correlate ($r = 0.96$; $p<0.05$). Individually, the correlations were similar ($r = 0.97$; $r =0.98$; $r =0.97$ and $r =0.97$ for participants 1, 2, 3 and 4 respectively) with a $p<0.001$ for all correlations. No correlation was found between trunk angular velocity and measurement differences between the two systems.

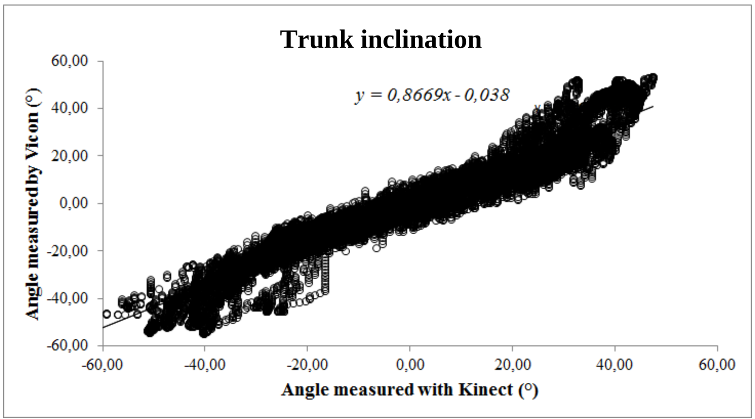

Figure 3. *Pearson correlation for the trunk inclination angle measured with Kinect and motion analysis system.*

A good correlation ($r = 0.85$; $p<0.05$) was observed between the ankle distance measured with Kinect and with motion analysis system. Individually, correlations were high ($r =0.86$; $r =0.85$; $r =0.88$ and $r =0.98$, $p<0.05$).

The child with CP who played the AVG verbally reported that the game was a little difficult. The child reported that the water drops were falling too far on each side to be able to catch them and that they were falling too fast.

4. DISCUSSION

This study presents a new AVGC combining the Wii Fit board and the Kinect to solicit M/L weight shifting in response to visual stimuli in a functional context. The AVGC use the CoP measured by the Wii Fit board as a controller to move the bowl from one side to the other. Plus, the Kinect allows the quantification of trunk movement during M/L weight shifting. To our knowledge this is the first active video game combining these two devices.

The lateral trunk inclination was measured using a Kinect. Our results showed a high association between the motion analysis system and the Kinect measurements. The trunk inclination threshold was fixed based on previous results comparing strategy of M/L weight shifting in children with CP and typically developing children (Ballaz et al, 2014). Our data demonstrated a high correlation in a range of 40 degrees of trunk inclination. Our results supports the results from Clark et al, (2012) who compared the maximal trunk inclination measured with the Kinect and an optoelectronic motion capture system during functional reach test.

The experiment with the CP participant showed the ability of this integrated multi-sensors system to function in gaming context. The child with CP reported that the water drops were too far on the sides and that this parameter increased the difficulty of the game. It is important to note that the game was not calibrated to take into account the participant base of support width. As mentioned previously, the width of the participant's base of support can greatly vary in a rehabilitation context. Furthermore, weight shifting amplitude is related to the base of support width, a larger base of support allows a greater weight shifting amplitude. The participant's feedback highlights the importance to take in account the base of support width in the game setting. The high correlation reported in the present study between the ankle positions defined with the Kinect and the ankle positions defined with the optoelectronic motion capture system, let us consider that the Kinect is an efficient tool to quantify base of support width. Further studies are required to confirm this point and also to establish a relation between ankle distance and base of support width. Indeed, depending on the foot shape, the ankle position does not exactly represent the limit of the base of support. Eventually, it would be pertinent to calculate the base of support width continually while participants play on the AVGC, because foot movements are expected during the game. On the other hand, our results should be taken precociously, the correlation coefficient do not allow quantifying systematic bias with Kinect measurement. Further analysis should be performed to answer those limitations.

Further research should validate the estimation of distance between the ankles in children with CP. They often have foot deformities and joint contractures in the lower limbs that may compromise the estimation of ankle distance by the Kinect.

Moreover, the child with CP reported, after playing at the game, that the water drop falls were too fast. The game was developed to alter the velocity of the water drops depending on the functional level of the player. This result put in perspective that further studies should be performed to define the optimal velocity of water drops to adapt the game for people with impaired motor function.

5. CONCLUSION

An active video game combining the Wii Fit board and the Kinect is a promising way to assess visually guided weight shifting ability. This project also demonstrated that the Kinect is an effective tool to measure the distance between the ankle and the trunk inclination.

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Evidence-based facial design of an interactive virtual advocate

W A Powell[1], T A Garner[2], D Tonks[1], T Lee[1]

[1]School of Creative Technologies, University of Portsmouth,
Winston Churchill Avenue, Portsmouth, UK

[2]Centre for Child Protection, University of Kent,
Giles Lane, Canterbury, UK

wendy.powell@port.ac.uk, t.garner@kent.ac.uk, daniel.tonks@port.ac.uk,thomas.lee@port.ac.uk

[1]*www.port.ac.uk*, [2]*www.kent.ac.uk*

ABSTRACT

RITA (Responsive InTeractive Advocate) is the vision for a computer software-based advocacy and companion service to support older adults and provide an alternative to institutional care. The RITA service will offer a preventative care approach, creating a digital champion who will learn an individual's needs and preferences over time, and be a friendly interface between users, family and professionals. This will involve the integration of a variety of technical components: *(1) The Face* - a realistic and emotionally expressive avatar, encouraging communication and interaction; *(2) The Mind* - a repository to store, organise and interpret personal and memory-related information representing the "essence" of a person, with user-defined access controls; *(3) The Heart* - an empathetic sensory interface which is able to understand and respond to the physical, emotional and psychological needs of the user. Each of these aspects presents a series of technical challenges, which will be addressed by combining existing state-of-the art techniques from a variety of disciplines, together with innovative processes and algorithms, to improve and extend functionality. RITA is being designed in consultation with user groups and service providers, and drawing extensively on existing research to inform the design and functionality of the system. In this short paper we introduce the design and development of the face of RITA.

1. INTRODUCTION

Around 3 million over 65's in England and Wales live alone (ONS 2011), with over half suffering from long-term health or mobility issues. Increasingly pressured lifestyles place burdens on extended family, restricting the opportunities for care and support (Merrill 1997; Silverstone and Hyman 2008), and increasing demands on the social care system mean that it is unable to address many of the issues associated with social isolation. Frequent changes between carers, alongside poor communication (across a fragmented healthcare system) presents a significant challenge in the provision of personalised support which is responsive to the needs, preferences, history and personality of an individual.

RITA (Responsive InTeractive Advocate) is the vision for a computer software-based advocacy and companion service that brings together three elements: a 3D virtual avatar and conversational agent, an 'essence' repository for storage and organisation of various forms of information pertaining to the user, and an empathetic communication system that is capable of understanding and responding to the psychological, social and emotional needs of the individual user. It is the first of these elements with which we are concerned here.

2. AVATAR CHARACTERISTICS: REQUIREMENTS AND EVIDENCE

Although it is recognised that visual rendering of an avatar influences the users perception of the characters personality (Dryer 1999), there is often a lack of systematic and informed design of virtual agents (Gulz, 2005; Gulz and Haale, 2006). Perception of character is subject to multiple and diverse influences, ranging from character type to clothing, facial expression to body language (Gulz 2005) and thus it can be challenging to decide on individual characteristics for any given avatar. However, a clearly defined purpose, together with elicitation of user requirement, can facilitate the process of meaningful and effective avatar design. The RITA animation team worked closely with a health care service design company in order to identify the key personality characteristics required for the RITA avatar. The main characteristics identified were *trustworthiness* and *competence*.

The first consideration was whether the avatar should be human or non-human, and the level of realism necessary. Whilst animal or other non-human characters can be perceived as friendly and engaging, human characters are considered to be more attractive (Schneider et al, 2007). Research within this area is currently lacking in fully evidenced conclusions with regards to the more highly-specific questions, such as: W*hat are the advantages of using a human avatar within a healthcare and wellbeing context? Does a human avatar evoke a greater sense of professionalism and competence?* We can make a certain degree of inferences from the various existing healthcare-associated avatar products, the majority of which are human in design (see Osaine[1], Cisco[2]).

The Uncanny Valley theory (Mori, 1970; Mori et al, 2012; Tinwell, 2011) suggests a danger in that increasing the human realism of a character may lead to a sense of discomfort if the end result looks almost, but not quite, human. In light of this, the avatar is based on a human character but using techniques to maximise the realism and visual fidelity, in order to reduce the sense of discomfort whilst optimising the required characteristics.

There are a number of factors which have been identified as being key elements defining the character of virtual agents, including movement and hand gestures (Johnson, Rickel and Lester, 2000), voice and verbal communication (Nass et al, 1994; Cassell et al, 2000), facial and emotional expression (Lester et al, 2000), and facial characteristics (Gulz 2006). The notion that perception of character can be drawn from the face has remained a popular cultural belief over the centuries (Berry and McArthur, 1986) and it could be asserted that a personality profile can be projected onto a person based upon an observer's perception (physiognomic stereotyping, see Hummert et al, 2014). The face is a powerful communication tool in which the majority of human expressions are formed during conversation (see Argyle 2013). Consequently, the RITA avatar will initially be displayed from the neck upwards. This maintains the key features necessary for engaging interaction, whilst reducing the computational load required for high fidelity realistic animation of a full-body avatar. In light of this, the key features for consideration in avatar design will be facial characteristics, voice and facial expression.

2.1 Facial Characteristics

It is clear that people make enduring judgements of character based on less than one second of exposure to a face (Todorov 2008). The perception of trustworthiness and competence appears to be based on variations in a few key facial features, summarised in Table 1.

Table 1: *Facial features associated with trustworthiness and competence.*

Feature	Competence / Dominance	Trustworthiness / Honesty
Face shape	Not too round (Oosterhof 2008, Poutvaara 2009) Angular or square face (Zebrowitz 2008)	Round or baby face (Kleisner, 2013) Smooth smaller face (Todorov, 2013) Fatter face (van Vugt 2006) Pronounced cheekbones (Todorov, 2013)
Chin	Wider chin, not too round ((Zebrowitz 2005)	Wide chin (Todorov, 2013) Rounder broad chin (Kleisner, 2013) Shorter chin (Kleisner, 2013)
Nose	Bridge not pronounced (Zebrowitz 2008)	Slim nose with shallow nose sellion (Todorov, 2013)
Mouth	Thinner lips (Zebrowitz 2008)	Broad mouth (Kleisner et al, 2013) Smiling or upward corners (Kleisner et al, 2013)
Eyebrows	Lower brows (Zebrowitz 2008)	High inner eyebrows (Todorov et al, 2013) Eyebrows closer together (Kleisner et al, 2013)
Eyes	Not too round (Zebrowitz 2008)	Brown eyes (Kleisner 2013) Large, open eyes (Todorov et al, 2013)
Hair	Brunette (Kyle 1996)	No data

Based on combining the key attributes from the available evidence, the initial facial mesh was constructed with a fairly round face shape, but with a wider than average jaw, slightly pronounced cheekbones and with the more angular features slightly softened. The mouth is slightly broad, with an upward turn at the corners. The nose is slim and with a shallow sellion. The inner brows are slightly higher than average and not too far apart, with the brow ridge being less pronounced, resulting in less shadow on the eyes, creating an impression of brighter and more open eyes (Figure 1a).

Figure 1. *(a) The base facial mesh designed for competence and trustworthiness (b)Actress engaging in motion capture process (c) emotions from actress animated on the base mesh (d) textured avatar.*

2.2 Voice

The RITA avatar voice has two elements to consider, accent and tonal quality. The latter is dependent on context, emotional overlay and speech elements, but the characteristics of the accent persist through all dialogue and therefore warrant some consideration. The cultural variation that would likely dictate users from alternative ethnic backgrounds would possess different vocal preferences for their RITA (see Kooshabeh et al, 2014) suggests that, in an ideal scenario, the vocal characteristics of RITA would need to be fully customisable to best suit the individual user. Within the current stage of development however, we are required to focus upon a single accent. Research by Tamagawa and colleagues (2011) suggests that, within healthcare robotics, there is a significant user-preference towards regional-sounding accents. Within the UK, a 2009[3] survey reported Received Pronunciation as the most appealing when speaking to a call centre, followed closely by a Scottish accent. Specifically, the Edinburgh accent has been associated with pleasantness and prestige[4] BBC online[5] published the results of an opinion poll that positioned Scottish accents as the 'most reassuring' during an emergency and accents from this region are largely connotative of competence, trustworthiness and friendliness. In light of this evidence, a Scottish actress was employed to provide source recordings as the basis for the voice of the avatar (Figure 1b).

The base mesh for the face was built in Autodesk Maya. A bone-based animation system drives the movements of the neck, jaw and eyelids, and blend shapes applied to simulate the macro and micro movements of the facial musculature. Once the mesh was fully rigged, the team used specialist facial capture software (Faceshift) to record facial movements and emotional expression from the actress. Animations were split into core speech and emotional state segments, before being imported into Maya and applied to the facial rig and refined by hand to optimise the fidelity (Figure 1c).

4. INTERACTION AND ONGOING DEVELOPMENT

The animated avatar is deployed in the Unity engine to allow real-time control of the avatar in response to signals from the control software. In order to build a modular and adaptable system, the "heart" and "mind" software send information to a decision-making system which will interpret the information relating to the users emotional and physiological state, personality and preferences, sending instructions to Unity to trigger the avatars response. Animation segments are coded and can be dynamically blended with emotional expression and audio files in order to generate appropriate speech, facial expression and synchronised speech.

The essence database is being developed and extended, and will be integrated with learning algorithms in order to populate itself over time as it interacts with the end-user. The modular RITA system can evolve over time, integrating developments in natural speech synthesis, data interpretation and emotional and physiological sensing. The project team engage regularly with service providers and service users in order to refine the capabilities and potential of the RITA advocate.

Acknowledgements: This research is supported by the Technology Strategy Board (Long Term Care Revolution). We thank our colleagues on the RITA project, Dr Jane Reeves (University of Kent), Dr Blair Dickson (Affective State Ltd) and Dr Valerie Carr (Snook) who provided insight and expertise to support the design of the avatar

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[2]The Medical Quack http://ducknetweb.blogspot.co.uk/2009/10/cisco-and-healthcare-technology.html

[3]*Reuters* http://uk.reuters.com/article/2009/11/24/us-britain-branding-accents-idUKTRE5AN37C20091124

[4]*BBC Polls* http://www.bbc.co.uk/voices/yourvoice/poll_results3.shtml

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Study of geometric dispatching of four-kinect tracking module inside a Cave

S Salous, T Ridene, J Newton, S Chendeb

CiTu paragraphe, Paris 8 University,
2 Rue de la Liberté, 93200 Saint-Denis, FRANCE

saleh.salous@citu.fr, safwan.chendeb@citu.fr, taha,ridene@citu.fr

http://www.citu.info/, http://www.univ-paris8.fr/

ABSTRACT

In a virtual reality application that requires the user to interact with his environment and in the context of an application inside a virtual reality room (CAVE) there is an ever increasing need to optimize the interaction cycle in all its steps, especially in the tracking step. Many existent tracking systems are used inside CAVEs, in this paper we propose a study of geometric dispatching of four-kinects inside a CAVE to be used as a tracking module for virtual reality applications.

1. INTRODUCTION

Over the past few years, Virtual Reality (VR) has become a rapidly growing domain and a promising platform (Tanriverdi et al, 2001, Allison et al, 1997). Virtual reality enhances and increases interactivity and immersiveness for many applications and domains (Richard, 2000, State et al, 1996, Manseur 2005, Hodges et al, 1995, Wyk 2009).

Users in Virtual reality can make powerful actions such as exploring, modifying, navigating, training, feeling, moving and playing as in the real world (Oliveira et al, 2006, Qureshi et al, 2007). Those user actions are monitored frame-by-frame through interaction cycles (see Figure 1 (left)) which are directly linked to the Virtual Reality context and environment, especially on the tracking step. In our case we are building virtual reality applications inside a CAVE (named the "SAS") (see. Figure 1) (right). The tracking step, inside the "SAS" is based on an ART-Tracking[1] module. One can refer to TerraDynamica[2] project for some results of our applications.

In our current work described in this paper we present our design of a new tracking system for a Virtual Reality room (the "SAS") based on a multi-kinects module. The next section briefly presents existent multi-kinects module. Section 3 deals with the proposed multi-kinect module for the "SAS". Finally we will conclude with a short outlook in section 4.

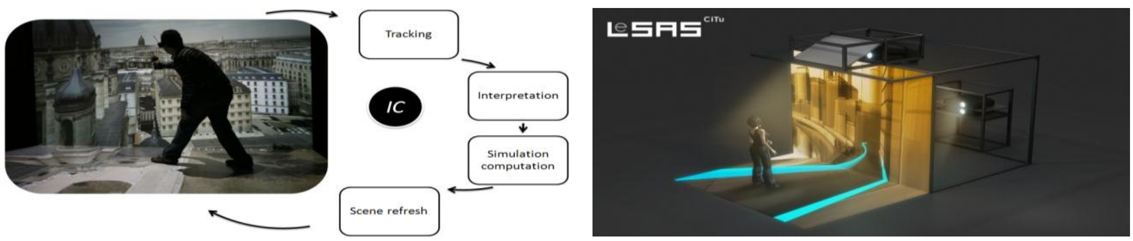

Figure 1. *(Right) Interaction Cycle – (3D Virtual City Visit – project TerraDynamica). (Left) "Le SAS": an immersive room with a wall screen and a floor screen.*

2. MULTI-KINECTS STATE OF THE ART

Many approaches use multi-kinects as a solution in their applications. Here are various examples. Kainz *et al* (2012) Use the data provided by multi-kinects to recreate a 3D representation of an object or a person for various purposes such as augmented reality or full-body scanning. Satta *et al* (2012) Use multi-kinects as an identification tool to recognize persons within kinects' range. Sumar (2011) Collect data from multi-kinects for the creation of a real-time image processing application. Faion *et al* (2012) Develop an application to scan objects or persons based on multi-kinects and to apply this, they develop an algorithm that determines what Kinects are the closest to them and deactivate the others'IR streams to reduce interferences in a multi-kinects configuration. Correia (2013) uses multi-kinects to tracks users as part of a musical application that produces music according to the users' movements and the movements of modded smartphones. Tong *et al* (2012) Built a system to scan 3D full human bodies using multi-kinects, in this system each kinect sees a specific part of the human body; three kinects can cover the entire human body with minimum overlapping between kinects. Ruhl *et al* (2011) Use RGB and IR kinect cameras to capture gas flows around objects in the flow using three kinects inside a lab room. As we can observe, in existent literature, the multi-kinects module was never proposed in case of the "SAS", in virtual reality context (see. Figure 2).

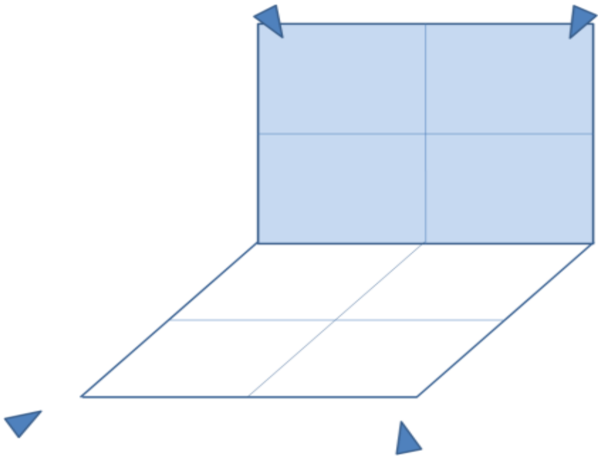

Figure 2. *This is a representation of the "SAS" with the location of the four Kinects.*

3. PROPOSED APPROACH

3.1 Global Idea

In our case we propose to build a four-kinects module for tracking inside a CAVE (see. Figure 2). Using multi-kinects has more than one advantage: relatively high coverage space, low cost compared to ART-Tracking (multi-Kinect module has 10% of the cost of ART-Tracking module) and feasible. Taking into account the horizontal and vertical FOV of a single kinect (see. Figure 3), we dispatch the kinects inside the "SAS" with the maximum of coverage. The orientation of the kinect sensor should be taken into account with high accuracy. But we have to deal with some usual problems such as interferences between kinects, for example by adding a motor that cause vibrations Maimone *et al* (2012).

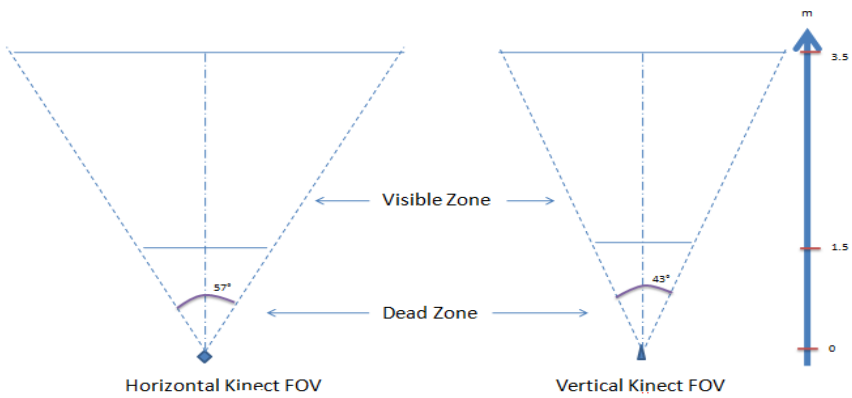

Figure 3. *FOV Kinect horizontal, vertical, visible zone and dead zone. Horizontal FOV: 57 degrees, Vertical FOV: 43 degrees, Tilt angle: from -27 degrees to 27 degrees, Range: from 1.2 to 3.5 meters.*

3.2 Geometric dispatching

Kinect has certain horizontal and vertical FOV as in **Error! Reference source not found.**. The way the multiple kinects have been dispatched implies overlapping areas; Figure 4 represents an example of overlapping between two kinects inside the "SAS".

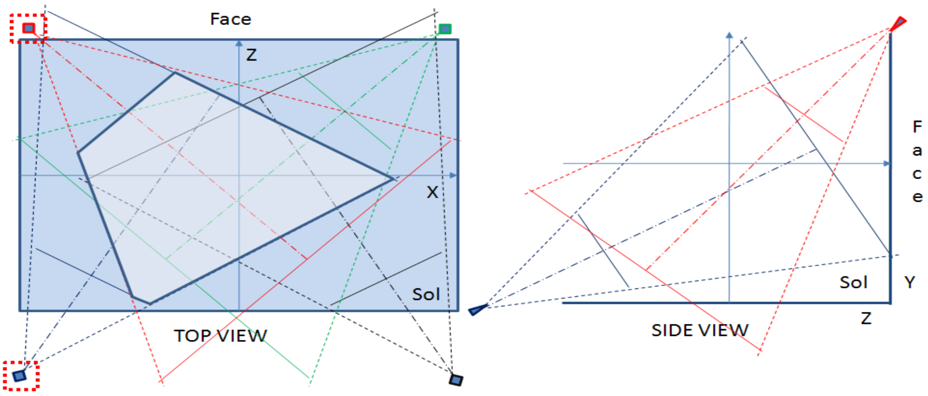

***Figure 4**. Overlapping area between upper-left and lower-left Kinect.*

Parts of the "SAS" will be covered by several kinects at the same time (see Figure 5), and combining the kinects' FOV allows us to determine how the server will manage the tracking of the users (some kinects can be temporarily disabled if there is no one in their FOV for instance) and how the fusion algorithm will proceed. Figure 6 explains a tracking example inside the "SAS". For reasons of efficiency, processing speed and reduction of IR interference, it may be necessary not to let all kinects function simultaneously at all times. This is why we have to define the overlapping areas between the kinects. Our objective with the analysis of the overlapping areas of the "SAS" is to provide data to determine the coverage of the kinects, and therefore, the effectiveness of the dispatching we proposed.

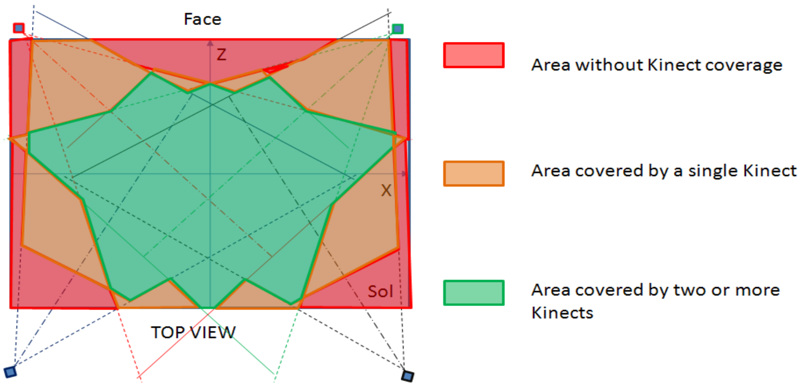

Figure 5. *Classification of the overlapping areas according to their level of reliability. Red spots are unreliable because no Kinect covers them; Orange zones have an average level of reliability as only a single Kinect has access to those; Green areas are the most reliable given that they are in two or more Kinects' FOV.*

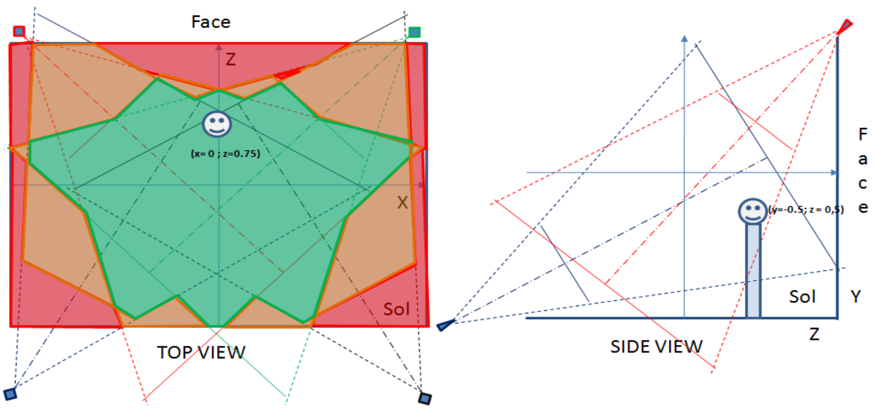

Figure 6. *Example of a successful attempt at tracking a user in the "SAS"*

4. CONCLUSION

In this paper we presented a study of an optimized geometric dispatching of a four-kinects module. This module is used as a tracking module in an interaction cycles for virtual reality context, in our case inside a CAVE "the SAS".

Our system is still in its beta version, and we need to build the fusion roles and to make a test of this module in real application. We also need to perform a quantitative study of comparison with our existent ART-Tracking system.

Acknowledgement. The works reported in this paper were in part conducted and sponsored as part of the *CapDigital* Business Cluster *TerraDynamica* project.

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[1]www.ar-tracking.com
[2]www.terradynamica.com

Harnessing the experience of presence for virtual motor rehabilitation: towards a guideline for the development of virtual reality environments

T Schüler[1], L Ferreira dos Santos[2], S Hoermann[3]

[1]Institute of Computer Science, University of Osnabrück,
Albrechtstraße 28, Osnabrück, GERMANY

[2]Rehabilitation Robotics Group (Fraunhofer IPK/ TU Berlin) &
DFG Research Training Group prometei, Technische Universität Berlin,
Marchstraße 21, Berlin, GERMANY

[3]Department of Medicine (DSM) & Department of Information Science, University of Otago,
60 Clyde Street, Dunedin, NEW ZEALAND

thschuel@uos.de, *lsantos@zmms.tu-berlin.de*, *simon.hoermann@otago.ac.nz*

[1]*www.inf.uos.de,* [2]*www.prometei.de,* [3]*www.otago.ac.nz*

ABSTRACT

The experience of presence has been shown to be important for virtual motor rehabilitation. Despite its importance, current research and therapy systems often make only limited use of it. This article introduces a conceptualization of presence that provides a guideline for the implementation of virtual rehabilitation environments. Three types of visual feedback in virtual rehabilitation systems are linked to three dimensions of presence. In particular it is shown how movement visualization, performance feedback and context information correspond to the presence dimensions: spatial presence, involvement and realness. In addition, practical implications are discussed to support the development of future virtual rehabilitation systems and to allow better use of the experience of presence for virtual motor rehabilitation after stroke.

1. INTRODUCTION

Virtual reality (VR) systems have been shown to be effective for the treatment of patients with motor impairments; however, the exact characteristics that lead to improvements are not well understood and more research is still needed to optimize therapeutic outcomes and VR systems (Laver et al, 2011). In VR systems patients interact with virtual environments: their movement is tracked with specific devices and is often visualized as movements of a virtual avatar. Today it is not known exactly how features of a virtual environment impact upon treatment outcomes. However, a key role for motivation and general effectiveness has been assigned to the experience of presence. Presence is defined as the illusion of nonmediation and the feeling of "being there" in the virtual environment (Lombard & Ditton, 1997). Consequently patients who experience presence during VR-based treatment focus on the game world that demands active participation. Therefore effective training may be supported through presence, yet few studies have examined this in therapeutic VR application.

With this article we attempt to clarify the importance of presence for VR-based treatment of motor disabilities after stroke. We identify three distinct feedback types that are provided by virtual rehabilitation systems. These types match well with the three dimensional model of the presence experience proposed by Schubert et al. (2001). We discuss how the feedback types and presence dimensions may foster recovery of motor function and suggest practical implications that guide future development of virtual rehabilitation systems.

1.1 Dimensions of presence

Schubert et al. (2001) proposed a three dimensional model of the presence experience. They identified three distinct factors contributing to an overall experience of presence. These factors were spatial presence (construction of a spatial mental model of the VR), involvement (attention allocation and concentration on the VR) and realness (comparison of the VR experience against one in a physical world).

Spatial presence has been linked with embodied theories of cognition (Riva et al, 2010). Specifically the ability of a subject to act within a virtual environment (agency) is thought to determine a coherent spatial mental

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model of that environment. Importantly it is the subject's individual perception of action potentials rather than an objective availability per se that constitutes spatial presence. Factors that contribute to involvement include technical and human conditions (Schubert et al, 2001) as well as the attention towards a virtual environment. It can be influenced through the choice of hardware components, but it is also dependent on the subjects' motivation and interest. The realness dimension represents a comparison of the experience made in the virtual environment with a similar one in the real world (Schubert et al, 2001). The realness judgment is influenced by the level of detail and the vividness of the VR.

1.2 Motor rehabilitation after stroke

Stroke is one of the main causes of acquired adult disabilities. Motor impairments following stroke are treated mostly with physical and occupational therapy. The goal is to enhance cortical plasticity and motor (re)learning to restore motor function and to acquire coping skills. Traditional therapy approaches focus on peripheral sensorimotor stimulation using active and passive movements of the affected limb. Within these approaches, practice is the most important factor for learning motor skills and a combination of repetitive and variable movement execution is required (Carr & Shepherd, 2010). Intensive training needs high patient motivation and adherence, which is often difficult to achieve with neurologic patients due to rather high demands for little progress. Informing the patients about their performance and the overall rehabilitation progress therefore is an important feature of practice. Using virtual rehabilitation, this challenge can be mitigated due to the possibility to include performance information in a motivating game experience.

Recent therapy approaches focus on central sensory stimulation of the impaired brain areas and make use of a neurologic mechanism, which activates cortical motor areas by observation or imagination of movements. This allows patients after stroke to activate neuron pathways similar to those recruited to execute movements that they are physically not able to perform. Though details about the underlying cortical mechanism are still under debate, the effectiveness of observing movements in a mirror for motor learning after stroke has been proven (Thieme et al, 2012). Virtual reality systems can replicate and even exceed the capabilities of a traditional optical mirror and produce a stronger illusion of actions for central sensory stimulation (Regenbrecht et al, 2011; Hoermann et al. 2012).

2. INFLUENCING THE EXPERIENCE OF PRESENCE WITH VIRTUAL FEEDBACK

Only limited evidence about features of the VR design for specific rehabilitation effects can be drawn from the literature today (Ferreira dos Santos et al, 2013; Laver et al, 2011). So far no design standards have evolved. Furthermore the applied VR-systems are often considered as a whole technology and not examined in detail during clinical studies, which makes it hard to draw conclusions about the individual design features. However a need for shared design considerations has been stated before and research towards this has been presented by Doyle et al. (2011). Virtual rehabilitation systems provide different types of feedback to the patients. The features of a virtual environment can be separated into distinct groups of feedback. Each of these groups corresponds primarily to a certain presence dimension (Table 1). The three types of feedback will not always be used in virtual rehabilitation systems, but usually they will be implemented to enable a complete game experience.

Table 1. *Types of feedback with their corresponding presence dimension*.

Type of Feedback		Presence dimension
Movement visualization	<—>	Spatial presence
Performance feedback	<—>	Involvement
Context information	<—>	Realness

2.1 Movement visualization

The patients are represented in VR by means of movement visualization, where motor actions are captured and transferred to a graphical object that is synchronously animated. In many cases this object will take the form of an anthropomorphic avatar that is observed from a first- or third-person perspective. However, fictive or abstract objects can also be used. In order to orient themselves in the virtual world and to manipulate objects, patients need to identify with the movement visualization. Since the action potential of the environment is experienced through this representation, spatial presence will be evoked when the patients are able to enact their intentions with the movement visualization. The observation of movement visualization in virtual rehabilitation systems can have a direct effect on motor learning since it can lead to central stimulation of cortical motor areas. Neurophysiological studies have shown that observing virtual limbs' movements stimulates cortical activity similar to the observation of real limbs in a mirror (Dohle et al, 2011). It has been postulated that observation of virtual limbs can facilitate the functional reorganization of the neuronal systems directly or indirectly affected by stroke (da Silva Cameirão et al, 2011). Thus an additional motor learning effect may be achieved when performing and observing movements during training. We furthermore postulate that the experience of spatial presence modulates central stimulation of motor areas during observation of movement visualizations. When experiencing spatial presence, the subject attributes the observed virtual motor actions to itself and corresponding cortical areas will be stimulated. We hypothesize a positive correlation between spatial presence and central stimulation. Therefore spatial presence is of high importance for motor learning in virtual rehabilitation.

2.2 Performance Feedback

Performance feedback is usually considered one of the key features increasing the involvement in virtual environments. During the treatment, patients have to accomplish tasks and when they are successful they gain points or proceed to a more difficult level. The task as well as the points or level will be visualized in some way in order to add meaning to the patient's exercises and inform them about their progress. In terms of its relevance for motor learning, performance feedback can be further differentiated into knowledge of performance (KP) and knowledge of results (KR) (Carr & Shepherd, 2010). In traditional therapies, feedback is often given in terms of KP, leading to an internal focus on the correct limb positions and movements during task execution. However, Wulf (2007) demonstrated that an external focus on the effects that the trained movements should have in the environment is more effective for motor learning. Thus performance feedback should also focus on providing KR. Virtual environments are well suited to provide both, information about the performance and about the results, within a game experience. In this way performance feedback can be regarded as a motivational factor and may foster the patients' adherence to the training. By means of performance feedback, the attention of the patients will be drawn towards the VR and, assuming the patients are willing to succeed in the game, will increase their engagement and involvement. Thus the presence dimension of involvement is linked with the effectiveness of performance feedback by motivating and engaging the patients.

2.3 Context information

Finally context information will be displayed that pictures the virtual world. This information may resemble a naturalistic place or a fictive environment in which the patients' representative and the tasks are conceivable. Background objects and animations give the VR system the impression of a real environment that is not just a technical artefact for therapeutic purposes. Atmospheric sensory stimuli in the form of sounds can add to the vividness of the experience. An important goal of therapeutic treatment is the transfer of learned behaviour to everyday activities, which patients should be confident enough to perform. Virtual environments can display real world contexts and objects used in every day tasks so that the patients can associate the learning with situations from their daily life. The realness presence dimension relates to this kind of vividness of a VR environment. Depending on the treatment approach, virtual rehabilitation systems may display various types of contexts, naturalistic or fictive. However in each case the realness presence dimension will be determined by the amount and coherency of the provided context information and thus affect how well the therapy system establishes a real experience. If an everyday task should be learned the realness dimension may even point towards the possibility of transferring the training situation to daily life.

3. EXAMPLE OF PRACTICAL APPLICATION

A previous study tested the hypothesis that presence is important for motor learning (Schüler et al, 2014). The Abstract Virtual Environment for Stroke Therapy (AVUS) was used for the treatment of 5 upper-limb hemiparetic patients. The system visualizes movement in an engaging way with different levels of abstraction (see Fig. 1).

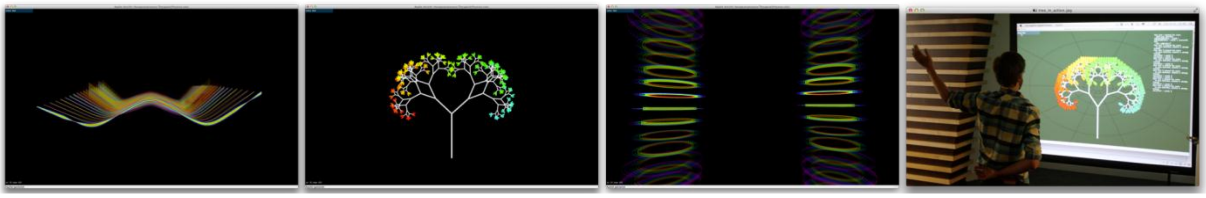

Figure 1. *Movement visualization with the AVUS system.*

AVUS is based on the assumption that observing abstract visualization of movements supports spatial presence and thus central stimulation of motor areas. The results of the preliminary study point towards the soundness of this hypothesis, by showing a suggestive correlation between the experienced sense of presence and the rehabilitation outcome as measured with a modified version of the Igroup Presence Questionnaire (Schubert et al, 2001) and the Fugl-Meyer motor assessment.

4. DISCUSSION

With this article we introduced a conceptualization of virtual rehabilitation systems that distinguishes between three types of feedback and attributed these to three presence dimensions. We suggested how the feedback types and presence dimensions may aid motor rehabilitation after stroke. We presented theories and preliminary study results that point towards the importance of presence for virtual rehabilitation and support our hypothesis that spatial presence modulates central stimulation of motor areas when observing movement visualizations.

Some practical implications can be drawn from our conceptualization. Movement visualization seems to play an important role for motor rehabilitation and should therefore be designed with special caution. While anthropomorphic shapes are used predominantly, there is also scientific rational to use more abstract forms and objects in order to develop a strong sense of spatial presence (Schüler et al, 2014). Future research should focus on clarifying the effects of movement visualization on the experience of presence and motor learning. Some kind of performance feedback is incorporated in most virtual rehabilitation systems. However since involvement in a VR-experience requires concentration, performance feedback should not be overloaded or distract the attention of the patients. Moreover what is judged to be motivating feedback is dependent on personality traits. This type of information should therefore be made adaptable. With regard to context information, the provided information should place the treatment in an appropriate context and allow the patients to have an optimized experience of the VR. Even though each of the three feedback types individually is suggested to have an influence on motor learning or transfer; combining them together will probably be most effective for therapeutic VR applications. Therefore we assume that a consideration of all interrelationships between feedback types and an optimized support of the sense of presence in the virtual environment is important for a holistic realisation of motor learning.

Acknowledgements: We thank Holger Regenbrecht for his feedback that helped to improve this manuscript.

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The potentiality of virtual reality for the evaluation of spatial abilities: the mental spatial reference frame test

S Serino[1], F Morganti[2], P Cipresso[1], E E R Magni[2], G Riva[1,3]

[1]IRCCS Istituto Auxologico Italiano,
via Pellizza da Volpedo, 41, 20149, Milan (MI), ITALY

[2]Department of Human and Social Sciences, University of Bergamo
Piazzale S. Agostino 2, 24129, Bergamo (BG), ITALY

[3]Università Cattolica del Sacro Cuore
Largo Gemelli, 1, 20100, Milan (MI), ITALY

s.serino@auxologico.it

[1]*www.auxologico.com,* [2]*www.unibg.it,* [3]*www.unicatt.it*

ABSTRACT

In recent decades, the use of Virtual Reality (VR) in the context of cognitive evaluation of dementia has considerably increased. The main objective of this preliminary study is to assess the feasibility of a VR-based tool for detecting deficits in using different spatial reference frames by comparing the performances of patients with probable Alzheimer's Disease (AD) with cognitively healthy controls. Although preliminary, our results showed the potentiality of using this VR-based tool to evaluate the ability in encoding and using different spatial reference frames.

1. INTRODUCTION

The ageing population (aged 65 and over) is projected to increase to 1.2 billion in 2025. Consequently, the prevalence of the dementia will significantly increase. Alzheimer's disease (AD) is the most common type of dementia, and it is estimated that the number of elderly affected will reach 81.1 million by 2040 (Ferri et al, 2006). Thus, the identification of early markers of cognitive decline in elderly population is now a worldwide health policy priority. In recent decades, the use of Virtual Reality (VR) in the context of cognitive evaluation of dementia has considerably increased (for a review, see (Bohil, Alicea and Biocca, 2011). VR technologies may be integrated in clinical and research settings to support the detection of early cognitive deficits by offering enriched environments with ecological but controlled demands (Riva, 2009; Rizzo, Schultheis, Kerns and Mateer, 2004). Precisely, VR offers the chance to easily control and manipulate the egocentric point of view to investigate the ability to encode and use different spatial reference frames. Indeed, spatial cognition may be defined as a high-level cognitive process based on two different spatial reference frames: an egocentric spatial frame in which object locations are represented relative to the individual and an allocentric spatial frame in which object locations are represented irrespective of the individual (Klatzky, 1998). Specifically, within the hippocampus, the CA3 region, receiving input from the entorhinal cortex, constitutes a cognitive model of the scene towards which the individual is drawn (namely, an allocentric view-point dependent representation) while the CA1 neurons, receiving input from the CA3 via Schaffer's collaterals, quickly encode abstract object-to-object information (namely, an allocentric view-point independent representation) (Behrendt, 2013; Robertson, Rolls and Georges-François, 1998). Accordingly, VR may be particularly useful for evaluating the cognitive profile of AD, since deficits in spatial cognition distinguish the first stages of this disease (Gazova et al, 2012; Lithfous, Dufour and Després, 2013). Nestor and colleagues (Pengas et al, 2010) who developed and tested a virtual navigation test— the Virtual Route Learning Test (VRLT)— for investigating spatial abilities in AD patients provided an interesting example. In this virtual test, participants are invited to learn four routes of increasing complexity. They are then required to retrieve the same route from memory but in reverse. The results showed that VRLT is able to detect spatial impairment in very early AD, as well as discriminate the AD patients from patients with Semantic Dementia. On these premises, we developed a VR-based tool – the Mental Spatial Reference Frame Test- to specifically evaluate the ability to encode and use different spatial reference frames. The main objective of this preliminary study is to assess the potentiality of utilizing this virtual tool to detect deficits in the use of different spatial reference frames by comparing the performances of patients with probable AD with cognitively healthy controls.

2. MATERIALS AND METHODS

2.1 Participants

Overall, 16 participants, 8 cognitively healthy participants (CG, control group), and 8 participants suffering from probable AD (probable AD) according to NINCDS-ADRDA criteria, participated in the study (McKhann et al, 1984). The probable AD group comprised 2 women and 8 men while CG included 4 women and 4 men. CG and probable AD participants were recruited from different social senior centers located in Lombardy, Italy. Individuals did not receive monetary reward for their participation in the study and was asked to sign the informed consent to participate in the study.

2.2 Spatial neuropsychological assessment

To evaluate the cognitive functioning of the participants in the study, the Mini Mental State Examination – MMSE - (Folstein, Folstein and McHugh, 1975) was administered. Moreover, the probable AD group was also assessed using Milan Overall Dementia Assessment - MODA- (Brazzelli, Capitani, Della Sala, Spinnler and Zuffi, 1994), a brief neuropsychological test developed to evaluate dementia. To specifically evaluate the spatial abilities, the following standard neuropsychological tests were administered: Corsi Block Test (Corsi, 1972; Spinnler & Tognoni, 1987) to measure short-term spatial memory (Corsi Span) and long-term spatial memory (Corsi Supraspan); Money Road Map (Money, Alexander and Walker, 1965) paper and pencil assessment of left-right discrimination that requires an egocentric mental rotation in space; Manikin's Test (Ratcliff, 1979) used to evaluate general mental rotation abilities by asking participants to evaluate in which hand a "little man" (showed with different views) was holding a ball; and Judgment of Line Orientation (Benton, Varney and Hamsher, 1978) neuropsychological test to assess visuospatial judgment. All scores obtained from these neuropsychological tests were corrected for age, education level, and gender according to Italian normative data. Detailed demographic and clinical characteristics of the two groups are reported in Table 1.

Table 1. *Mean scores at neuropsychological spatial assessment tasks reported by the two groups of the study.*

	Group	
	Probable AD	**Control Group**
Age	82.2 (6.69)	82.9 (9.12)
Years of Education	6.13 (2.8)	9.38 (4.81)
MMSE	23.1 (1.49)	28.7 (.965)
MODA	66.2 (9.66)	
Corsi Block Test - Span	4.19 (.91)	4.75 (.5)
Corsi Block Test - Supraspan	5.58 (1.24)	9.61 (2.86)
Money Road Map	17.6 (3.70)	19.4 (6.02)
Manikin's Test	17.00 (3.07)	26.00 (3.55)
Judgment of Line Orientation	6.38 (5.63)	15.63 (5.75)

2.3 Mental Spatial Reference Frame Test

The Mental Spatial Reference Frame Test consists of two main tasks that assess the abilities to encode and use different spatial reference frames. In the encoding phase, the participant is asked to navigate in a virtual room including two objects, that is, starting from the center of the room oriented toward North, he/she has to memorize the position of two objects. On the first task (Task 1), she/he is asked to indicate the position of one object on a real map (namely, a retrieval with spatial allocentric information independent of point of view). On the second task (Task 2), she/he is asked to enter an empty version of the same virtual room. The participant has to indicate position of the object, starting from the position of the other object (namely, a retrieval without any spatial allocentric information). In both tasks, the accuracy of the answer is the dependent variable [1= poor answer, for example, choosing the opposite of the virtual room (i.e., choosing the southern side when the object in the learning phase was in the northern part); 2= medium answer, for example bad left-right discrimination (i.e. the eastern part of the virtual room, when the object in the learning phase was in the western side); 3= correct answer)]. The entire procedure was repeated across three different trials. In the first trial, the object in the learning phase was on the East side, in the second trial the object was on the West side, in the third trial the object was on the South side. From a technical point of view, the Mental Spatial Reference Frame was created using NeuroVirtual 3D, a recent extension of the software NeuroVR (Cipresso, Serino, Pallavicini, Gaggioli and Riva, 2014; Riva et al, 2011), which is a free virtual reality platform for creating virtual environments useful for neuropsychological assessment and neurorehabilitation. The virtual environments was rendered using a portable computer (ACER ASPIRE with CPU Intel® Core™i5 and graphic processor Nvidia GeForce GT 540M). Participants also had a gamepad (Logitech Rumble F510), which allowed them to explore and to interact with the environment.

Proc. 10th Intl Conf. Disability, Virtual Reality & Associated Technologies
Gothenburg, Sweden, 2–4 Sept. 2014
©2014 ICDVRAT; ISBN 978-0-7049-1546-6

3. RESULTS

The data were entered into Microsoft Excel and analyzed using SPSS version 18 (Statistical Package for the Social Sciences–SPSS for Windows, Chicago, IL, USA). First, differences in neuropsychological tests of spatial abilities between groups (CG vs. Probable AD) were calculated using one-way ANOVAs. The results showed significant differences between the two groups in all tests, with the exception of the Corsi Block Test - span and the Money Road Map. Specifically, when compared to CG, probable AD participants showed poorer spatial abilities. Then, differences in the scores on the Mental Spatial Reference Frame Test were calculated using a repeated measure ANOVA (Bonferroni's adjustment): 2 Tasks (Task 1 vs. Task 2) × 3 Trials as within factors, and Group (CG vs. probable AD group) as between variable. The results showed a significant effect of Trials, $F(2, 26) = 5.48$, $p < .05$, $\eta_p^2 = .301$. Specifically, pairwise comparisons indicated that the average scores were significantly lower on the third trials ($M = 1.99$, $SD = 0.11$) compared to the first trials ($M = 2.55$, $SD = .12$). Second, the results showed significant differences between the two different Tasks, $F(1, 13) = 20.30$ $p < .001$, $\eta_p^2 = .610$. In particular, pairwise comparisons revealed that the average scores were significantly lower in the Task 2 ($M = 1.96$, $SD = 0.13$) compared to the Task 1 ($M = 1.96$, $SD = .13$). Although we found no significant differences between Groups, it is possible to observe a trend toward significance in the interaction Trials x Tasks x Groups $F(2, 26) = 2.70$ $p = .086$, $\eta_p^2 = .176$. In particular, probable AD participants performed poorer on the third trial of the Task 2 (see Figure 2).

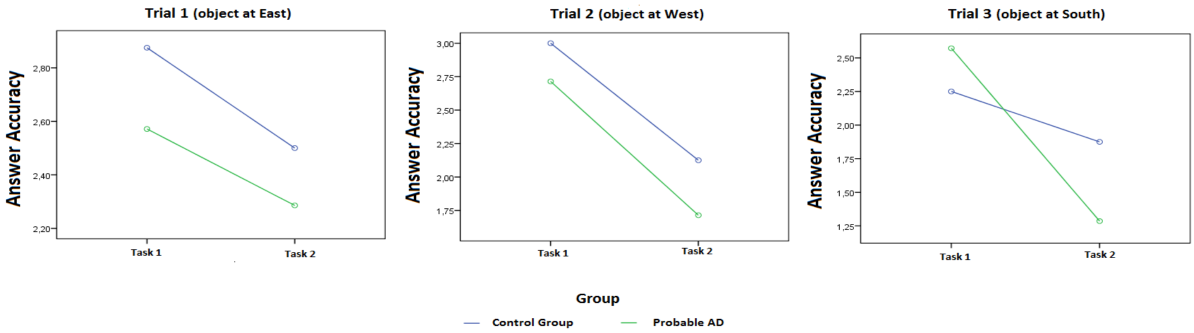

Figure 1. *Probable AD group performed poorer on the third trial (object in the South of the virtual room), especially in the Task 2.*

4. CONCLUSIONS

Due to the impressive growth of the ageing population, the identification of cognitive markers to characterize the profile of AD has been recently the focus of considerable research interest. In this direction, our main objective was to investigate the potentiality of using the Mental Spatial Reference Frame Test in the traditional neuropsychological evaluation of spatial abilities in patients suffering from probable AD. First, as expected, our results confirmed that probable AD patients were impaired in the traditional neuropsychological evaluation of spatial functions when compared with the control group. Concerning the results from the Mental Spatial Reference Frame Test, our findings showed that all participants were less accurate in completing the third trial, significantly when compared to the first one. The third trial may have been more difficult since the object was presented at the South end of the virtual room in the encoding phase, requiring a complete spatial rotation to retrieve it. Moreover, our results showed that all participants performed poorer on Task 2 when compared to Task 1. While the Task 1 measured the ability to encode and store an allocentric reference frame by asking participants to retrieve the position of the object on a real map, the Task 2 evaluated a more complex spatial ability, since the participants were required to indicate the position of the object in an empty virtual room without any spatial allocentric information. Indeed, to solve the Task 2, it was necessary to retrieve the object-to-object abstract cognitive representation of the scene and impose on it a new egocentric view- point. According to Burgess and colleagues (Byrne, Becker and Burgess, 2007), an effective spatial orientation in the surrounding environment requires a translation from a long-term allocentric reference frame to an egocentric one. Starting from this model, Serino and Riva proposed that for an effective translation between allocentric and egocentric spatial reference frames, it is crucial that allocentric view-point independent representation has to be synced with the allocentric view-point dependent representation (Serino & Riva, 2013, In press). From this perspective, our findings showed that probable AD participants performed poorer on the third trial of the Task 2, that is, when they were required a complete mental rotation, they showed a deficit in the synchronization between the allocentric view-point independent representation and the allocentric view-point dependent representation. A break in the "mental frame syncing", underpinned by damages to hippocampus, may be a crucial cognitive marker both for early and differential diagnosis of AD (Serino & Riva, 2013). The findings of this preliminary study are interesting, although some limitations should be acknowledged. First, the sample size was very small.

Moreover, it would be interesting to replicate this study using an immersive VR set-up. Future studies should investigate whether the detection of subtle spatial deficits could be used to identify individuals most at risk for progression to AD.

Acknowledgements: This study was partially supported by the research project "NeuroVirtual 3D" funded by Regione Piemonte (Grant No. FA 211-432C- 2012).

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Improved mobility and reduced fall risk in older adults after five weeks of virtual reality training

S R Shema[1], P Bezalel[1], Z Sberlo[1], O Wachsler Yannai [2], N Giladi[1,3,4], J M Hausdorff[1,4,5,6], A Mirelman[1]

[1]Laboratory for Gait and Neurodynamics, [2]Department of Physical Therapy, Tel Aviv Sourasky Medical Center, Tel-Aviv, ISRAEL

[3]Sackler Faculty of Medicine, [4]Sagol School of Neuroscience, [5]Department of Physical Therapy, Tel-Aviv University, Tel-Aviv, ISRAEL

[6]Harvard Medical School, Boston, MA, USA

[1]*shirleys@tlvmc.gov.il*, [2]*anatmi@tlvmc.gov.il*

[1]*www.tasmc.org.il*

ABSTRACT

The aim of this analysis was to assess whether 5 weeks of training with virtual reality (VR) in a clinical setting can reduce the risk of falls in a variety of older adults. Thirty-four participants attending the VR clinic were studied. Participants underwent 15 training sessions consisting of walking on a treadmill with a VR simulation. Significant improvements were observed in gait speed, the Four Square Step Test and the Timed Up and Go. Treadmill training with VR appears to be an effective and practical clinical tool to improve mobility and reduce fall risk in older adults.

1. INTRODUCTION

Normal and safe mobility depends on intact sensory and motor systems, but there is a growing body of research that specifically links the cognitive sub-domains of attention and executive function (EF) to gait alterations and fall risk (Springer et al, 2006; Yogev-Seligmann et al, 2008). EF apparently plays a critical role in the regulation of gait especially under challenging conditions where decisions need to be made in real-time and constant adaptation is required to manage internal and external factors (Ble et al, 2005). External factors can include, for example, obstacle crossing or attending to multiple tasks during walking. The performance during more demanding daily activities, such as walking while performing a simultaneous task (i.e., dual or multi task) or obstacle negotiation, plays a key role in the safety and well-being of a variety of individuals with either motor and cognitive dysfunctions (Beauchet et al, 2005; Shumway-Cook and Woollacott, 2000). Thus, interventions which focus on a combined motor-cognitive approach may improve gait and decrease the risk of falls.

Previous studies on the use of VR for training of balance, gait and fall risk in older adults and individuals with neurological disorders have shown positive effects on walking speed, stride time and step length as well as in the ability to perform dual task and obstacle negotiation as compared to training in conventional balance training groups (Buccello-Stout et al, 2008; de Bruin et al, 2010; Mirelman et al, 2010). Studies have also shown improved dual task ability and cognitive function after the use of motor-cognitive rehabilitation using VR (Mirelman et al, 2011a; Mirelman et al, 2011b). Recently we have also shown positive effects of using VR as a clinical service (Shema et al, 2014). The effects of VR on the risk of falls in older adults are unknown.

The ‘Timed Up and Go’ test (TUG) (Podsiadlo and Richardson, 1991) is a quick and widely used performance-based measure of mobility. The TUG has been extensively studied in older adults (Hatch et al. 2003;Shumway-Cook et al. 2000) and recommended as a simple screening test of fall risk. TUG duration has also been associated with cognitive function (Donoghue et al, 2012a; Herman et al, 2010). More specifically, older adults with better executive function and attention performed the TUG more quickly (Donoghue et al, 2012b; Herman, Giladi and Hausdorff, 2010). Previous work has demonstrated the added value of using body-worn sensors to augment the traditional TUG (Mirelman et al, 2014). Thus the aim of this analysis was to assess whether 5 weeks of training with VR in a clinical setting can reduce the risk of falls as measured using the instrumented TUG and other tests of mobility in a variety of older adults with gait impairments.

2. METHODS

2.1 Participants

The current retrospective data analysis reviewed the medical records of 34 participants (mean age 74.51 ± 10.51 years, 56% women) attending a gait rehabilitation program at the VR clinic in the Tel Aviv Sourasky Medical Center. The study was approved by the local institutional human studies committee. All participants were referred to the clinic by their physicians. Indications for referral included recurrent falls, fear of falling, complaints of gait instability or recent deterioration of gait, mainly but not exclusively due to neurological etiology. Participants were eligible for the training program if they were: 1) able to walk independently for at least 5 minutes with or without walking aids; 2) did not have any cardiac contra-indication for moderate training intensity; and 3) did not have severe visual loss that could interfere with their ability to see the VR simulation. Participants who could not follow simple instructions and those with dementia (as per DSM IV guidelines) or diagnosed psychiatric disorders were not eligible for the training program.

2.2 Training

Training was provided 3 times per week for 5 weeks with each session lasting about one hour. During the training, patients walked on a treadmill with a safety harness which did not provide body weight support. Two light emitting diodes (LEDs) were attached to the lateral side of the patients' shoes which served as the interface to the VR simulation that was projected on a screen in front of the treadmill. The virtual environment (VE) simulation included an obstacle course situated along different pathways in an outdoor scene. The various pathways differed in duration, number of intersections, and challenging segments which included bifurcations and walking on a bridge over a river. The virtual obstacles required negotiation in two planes: 1) vertical, to increase step clearance and 2) horizontal, to increase step length (see Figure 1). Difficulty levels were graded based on obstacle size and frequency of appearance as well as time of appearance requiring the participants to plan ahead, adapt their steps and select the correct negotiation strategy to avoid a collision. Feedback was provided by the simulation and consisted of knowledge of performance and knowledge of results. Training parameters were gradually increased from week 1 to week 5. Motor load was increased by adapting the treadmill speed, prolonging walking duration and decreasing the participants' hand support on the treadmill bars while walking. The VE parameters were progressed by presenting a wider range of obstacle sizes, increasing obstacle frequency of appearance, disrupting visual clarity and the addition of virtual distracters. Cognitive load progression was achieved by challenging sustained and divided attention, planning and reaction time.

Figure 1. *Two types of virtual obstacles were used, requiring patients to adjust proper step length and step clearance.*

2.3 Clinical Evaluation and Assessment

Gait speed was assessed before and after the training by measuring the time walk 10 meters. Obstacle negotiation was assessed using the Four Square Step Test (FSST). The instrumented Timed Up and Go (TUG) test was used to evaluate functional mobility, dynamic balance and fall risk (Shumway-Cook, Brauer and Woollacott, 2000). Participants wore a small, portable, light-weight body-fixed sensor (DynaPort, McRoberts BV, The Hague, the Netherlands) on their lower back secured using a neoprene belt. The sensor includes a triaxial accelerometer and gyroscope. Acceleration signals were derived from three axes: vertical, mediolateral, and anterior posterior. Angular velocities were derived from the gyroscope as yaw (rotation around the vertical axis), pitch (rotation around the mediolateral axis), and roll (rotation around the anterior-posterior axis). After testing was completed, data were transferred to a personal computer for further analysis. The TUG subtasks (sit-to-stand and stand-to-sit transitions, walking, and turning) were analyzed using an automated algorithm based on the anterior-posterior axis that was used for detecting the start and end times of the TUG (Weiss et al, 2011).

2.4 Data Analysis

Data was examined for normality and descriptive statistics were extracted for all clinical measures. Data was compared across time (i.e., before vs. after the 5 weeks of training) using paired t-tests or Wilcoxon Signed Rank test, as appropriate. Analyses were performed using SPSS version 21 with an alpha level of 0.05.

3. RESULTS

All participants finished all 15 sessions of training. No adverse events were reported. All subjects had a history of falls (mean 2.82 ± 4.16 falls in the 6 months prior to the study) and demonstrated a high risk of falls as reflected by the TUG pre-training (18.53 ± 9.08 sec). Gait speed improved after training (0.97 ± 0.26 m/s to 1.03 ± 0.28; p=0.025). Similarly, dynamic balance and obstacle negotiation (FSST) improved after training by 14% (from 17.34±6.77 sec to 14.92±4.99 sec; p=0.014).

Time to complete the TUG significantly improved demonstrating a decrease in fall risk (18.53 ± 9.08 sec to 16.77 ± 7.63 sec; p=0.008). Analysis of the subtasks of the instrumented TUG demonstrated that improvements in TUG duration stem from faster walking speed during the walking subtask of the TUG (10.5 ± 6.07 sec vs. 9.48 ± 5.57 sec; p=0.019), with decreased number of steps taken (20 ± 13.48 vs. 17.38 ± 11.61; p=0.009). In addition, the duration of the turn-to-sit was reduced after training (2.38 ± 0.89 sec vs. 2.12 ± 0.62 sec; p=0.043), reflecting lower angular velocity during the turns.

4. CONCLUSIONS

The study demonstrates that after 5 weeks of intensive treadmill training with VR, the participants preformed the TUG and the FSST faster, suggesting improved functional mobility. The improvements observed in after training further reflect an important decrease in the risk of falls at a group level. The use of wearable sensors to quantify the TUG and its subtasks provided insights into gait performance and the specific effects of the VR training. The results demonstrated that the subjects walked faster with an increased step length as reflected by the decreased number of steps taken. This finding is directly related to the trained tasks and demonstrated transfer of training effects. However, the results also revealed additional benefits in dynamic stability and planning as observed by the reduced turn duration.

Training with VR differs from usual gait training, as it contains cognitive aspects of planning, constant adaptation and shifting of attention under challenging motor conditions. As a combined approach, it promotes motor learning through problem solving, thus enhancing executive. The TUG and FSST present short yet relatively complex motor-cognitive tasks, demanding rapid changes in body alignment (i.e., turns or step direction) while maintaining balance. These tests are associated with cognitive processes, since they require subjects to remember and execute a timed motor sequence, involving motor planning and shifting, attributes that are needed for maintaining safe gait in daily living. Thus the present findings suggest that training with VR can promote both motor and cognitive function that can transfer to daily living activities and promote health.

We believe that the use of different virtual obstacles promoted greater clearance and increased step length contributing to the improved gait pattern. The virtual environment enabled a challenging training in a functional context, while maintaining patient safety which is valuable for the patient and the trainer. The ecological validity of the virtual simulation promoted motor learning as well as transfer of gains into real world performance. The findings suggest that after training, participants had better functional mobility and had decreased risk of falls. The study further demonstrates the utility of VR in a clinical setting in improving functional abilities and gait performance in a variety of older adults. A future analysis of a larger cohort, including subjects with additional musculoskeletal pathologies, may help to identify further indications for this program.

Acknowledgements: We would like to thank the participants of this study as well as Eran Gazit, Inbal Maidan, Moran Dorfman, Lior Yeshaayahu, Ricki Turgeman for their assistance in this study. This research was supported in part by the European Commission (FP7 project V-TIME- 278169) and by the Tel Aviv Sourasky Medical Center Grant of Excellence.

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Realistic and adaptive cognitive training using virtual characters

D Sjölie

Department of Applied IT, University of Gothenburg,
412 96 Gothenburg, SWEDEN

daniel.sjolie@ait.gu.se

www.ait.gu.se

ABSTRACT

Computer-aided cognitive training has the potential to be an important tool in the fight against dementia and cognitive decline but many challenges remain. This paper presents an example of how realistic and adaptive training may address these challenges. Virtual characters were used as stimuli in a dual n-back working memory task in a realistic 3d-environment. Support for continuous adaptation was a priority, including adaption based on affective states such as arousal.

1. INTRODUCTION

An increasingly older population around the world makes the need for methods to combat dementia and age-related cognitive decline increasingly urgent. Computer-aided cognitive training has been championed as one such method with great potential (Klingberg, 2010; Li et al, 2008). Unfortunately, recent research has shown that it is very difficult to achieve general cognitive improvements with cognitive training, i.e., transfer effects (Owen et al, 2010). This paper provides an example of how solutions building on an understanding of human brain function in realistic environments can be used to meet this challenge. The importance of realistic interaction and the ecological validity of training are fundamental motivations for the use of virtual reality (VR) for rehabilitation and training (Pugnetti et al, 1995; Rizzo et al, 2001).

The difficulty to gain general improvements from cognitive training is commonly described in terms of a distinction between near transfer and far transfer. Training a particular task very often leads to improvements on similar tasks (near transfer). Transfer to tasks with no clear similarity to the trained task, however, (far transfer) has proved difficult (Dahlin et al, 2008; Li et al, 2008). Much recent work on cognitive training has been focused on trying to get general improvements related to, e.g., attention or working memory. Such general improvements should result in improved performance in everyday tasks such as remembering what to shop but they require far transfer. One response to this difficulty of achieving far transfer is to focus on near transfer and on the need to train the right thing, e.g., using interactive systems with high ecological validity. Reality-based human-computer interaction (HCI) in general and virtual reality (VR) in particular provides a foundation for ecologically valid computer applications by building on the user's skills and experiences from reality (Jacob et al, 2008; Rizzo et al, 2004).

2. PREVIOUS WORK

2.1 *Cognitive training*

One form of cognitive training that has attracted much attention is working memory (WM) training. Working memory capacity predicts performance in a wide range of cognitive tasks, and many neuropsychiatric conditions such as stroke or attention-deficit hyperactivity disorder (ADHD) coincide with impaired WM (Klingberg, 2010). Several studies have shown that performance on specific WM tasks such as 2-back (comparing the last number in a sequence to the one presented 2 steps before) does improve with training and that this effect does transfer to similar (near-transfer) tasks (Dahlin et al, 2008; Klingberg, 2010; Li et al, 2008; Owen et al, 2010). However, the magnitude and range of transfer, in particular the potential for far-transfer, remains disputed. Studies comparing transfer effects in old and young adults have presented seemingly conflicting results. A study by Dahlin et al. concluded that while transfer to untrained tasks is possible for both young and old the magnitude varies and it is often harder to demonstrate transfer in old adults (Dahlin et al, 2008). In other studies transfer effects in young and old have been compared without any reliable differences (Li et al, 2008). More generally, Owen et al. (2010) failed to show any general cognitive improvements for 11,430 participants training on cognitive tasks online for several weeks. Suggested reasons for such results include variations in the amount and intensity of the training (sometimes with significant individual variance) as well as differences in the overlap between trained tasks and the evaluated transfer task.

Figure 1. *This task was inspired by the dual N-back task used by Jaeggi et al. (2008). The stimuli to keep track of is who (which of the characters) is/was doing what (which animation) N steps back.*

One common working memory training task is *n-back*. In a basic implementation of the n-back task the subject may be presented with a series of numbers and asked to compare each new number to the one seen n steps before. E.g., with n=1 the question is if the new number is the same as the last, with n=2 if it is the same as the number before the last, etc. This requires the subject to constantly remember n previous numbers and to update this list each time a new number is presented. The numbers can be exchanged for any stimuli. In the *spatial n-back* version subjects need to remember *where* a stimulus was presented n steps back, and compare it to the location of new stimuli. If the stimulus itself is also varied this becomes a *dual n-back* task, where the subject must remember and compare both position and identity. This is a very demanding cognitive task, providing one way to increase the intensity of the training. Training on a dual spatial n-back test with sound as the second stimuli has been shown to improve measures of fluid (i.e., general) intelligence (Jaeggi et al, 2008).

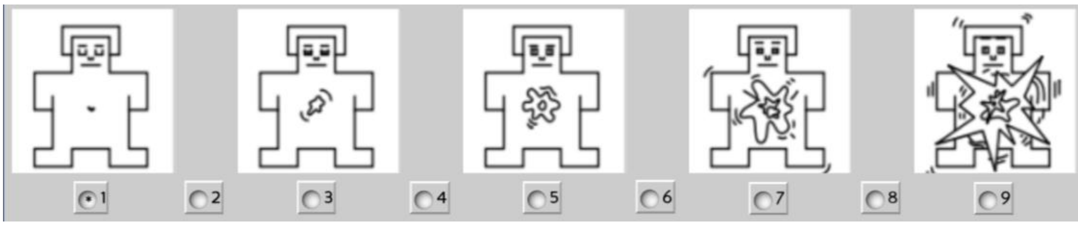

Figure 2. *The Self-Assessment Manikin (SAM) may be used to present a visual scale of affective dimensions to users to get quick responses. We used scales for arousal (shown here) and valence with 5 manikin images plus in-between scale steps.*

2.2 Presence and Synchronization for Virtual Rehabilitation

Presence has traditionally been described as the sense of "being there" in a virtual environment (Slater, 2002) but recent elaborations have a closer connection to cognition and the human brain. An emphasis on presence as hypothesis selection (Sanchez-Vives and Slater, 2005) connects to the importance of predictions and prediction errors in recent theories of brain function and presence as "the ability to act there" connects to the use of existing motor representations (Jäncke et al, 2009). The concept of *mental simulations* can be helpful in understanding why existing expectations and representations are so important and in getting a handle on how cognitive training can be designed with this in mind. Mental simulation includes unconscious and flexible reactivation of memories, employed to recognize the current context and to simulate, or predict, possible actions and expected results (Barsalou, 2008). The idea that predicting future events based on previous experience is a critical aspect of how the brain works has gathered increasing support in recent years. It is prominent in recent theories of cognition and brain function by Hawkins (2005), Friston (2010) and others. A recent paper by Clark (2013) provides a broad introduction.

Particularly interesting for presence and virtual rehabilitation is how this framework suggests that the brain essentially implements a running simulation of reality. This has prompted descriptions of presence as related to the synchronization between an external environment (real or virtual) and the subjective mental reality simulated by the brain (Sjölie, 2012). Related theories of brain function provide a basis for understanding how such synchronization develops and how we may design a virtual environment to facilitate synchronization of specific mental simulations, corresponding to cognitive skills. For example, the combination of familiar stimuli with a familiar context should provide an optimal foundation for internalization and adaptation of a specific task (i.e., learning).

3. REALISTIC COGNITIVE TRAINING

We have implemented a version of dual n-back task using a realistic 3d-environment with animated characters in order to increase the familiarity and realism of both the stimuli and the environmental context (fig. 1). The task is transformed to remembering which characters have made which movements over the last few steps. The moving character corresponds to the position and the different animations correspond to the second stimuli. Based on the reasoning presented above, learning to keep track of who did what just a minute ago, in a realistic 3d-environment, should have a greater chance of producing transfer to similar everyday situations than training using, for example, n-back with arbitrary images at different 2d positions.

Much effort was spent on making it possible to balance the difficulty of the training. A gamepad was used to provide a clear and simple interface with few buttons. Buttons on the front of the gamepad were used to answer the repeated n-back question of whether the stimuli were the same or not, with buttons on the right and left respectively for each question (what/who, see fig. 1). Normally, new stimuli is presented at regular time intervals but in order to reduce the risk of subjects giving up completely if they get behind we introduced an optional mode to wait for the subject to respond. This was coupled with feedback on late responses and a count of late responses. The feedback was very noticeable as the lighting in the entire virtual environment changed. Similar feedback was given in response to wrong answers. The duration of the regular time interval could also be changed to adapt the level of stress in the task. The application has been implemented using Panda3D, a full featured 3d game engine.

3.1 Adapting to Affective State

Synchronization and optimal training depends on a suitable level of prediction errors. According to activity theory (Kaptelinin and Nardi, 2012) any human activity is driven by a need to change something in the environment. Something important is not as we would prefer it to be, it does not match our “prediction” of the ideal world, and the mismatch arouses us to action. Based on such reasoning we attempted to measure the subject’s level of arousal throughout the training using Self-Assessment Manikin (SAM, fig. 2) questions at regular intervals.

In an attempt to provide automatic adaptation of the cognitive training we used a commercial EEG headset (Emotiv EPOC) to try to measure mental workload related to arousal. Data was collected over 13 trials with 4 subjects before data collection was aborted because of poor classification performance. The classification of the EEG data was not good enough to enable successful automatic adaptation for most users, but trends for selected subjects suggest that such adaptation may be possible given optimal conditions (fig. 3).

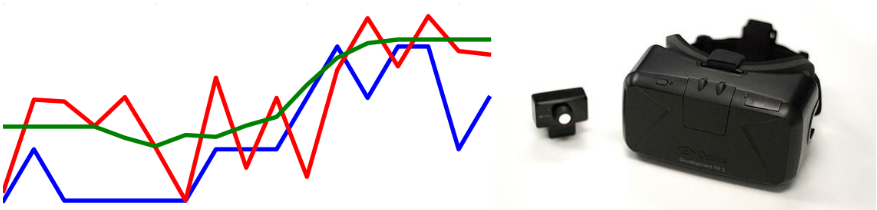

Figure 3. *Left: Example of classified arousal (red) and reported arousal (blue) based on EEG measurements. The Y-axis is arousal (on a 0.0-1.0 scale) and the X-axis is consecutive 1-minute task blocks over one trial. Notice the trend when classified arousal is smoothed (green). Right: The latest development version of the commercial and accordable Oculus Rift HMD*

4. FUTURE WORK

In order to further investigate the effect of the realistic and adaptive cognitive training presented here it needs to be compared to solutions with varying degrees of realism and adaptivity. Our system already implements more traditional n-back tasks such as images shown on different locations, in 2d- or 3d-space. This makes it possible to evaluate training with logically identical tasks while stimuli and environments vary in familiarity and realism. It is also possible to increase the realism of the environment and context by immersing the subject in the virtual environment using traditional VR technologies such as head-mounted displays (HMDs). The recent development of affordable HMDs (fig. 3) suggests that such systems may indeed become common in the near future. Support for the Oculus Rift is under development for the Panda3D engine used to build our application. Ideally, such different setups should be used to train a large number of subjects over a significant period of time, followed by an evaluation of the resulting transfer to different tasks, including everyday activities.

While the automatic adaptation using EEG failed initially the basic motivations for implementing such functions are valid and much remains investigate. Alternative psychophysiological measures such as galvanic skin response (GSR) or functional near-infrared spectroscopy (fNIRS) would be interesting to evaluate, and a combination of new headsets and improved training protocols may give EEG a new chance.

Acknowledgements: Thanks to Lars-Erik Janlert and Johan Eriksson for comments on the development of the prototype. Thanks to Kempe Foundations and Umeå University for funding.

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Performance analysis of adults with Acquired Brain Injury making errands in a virtual supermarket

E Sorita[1,3], P A Joseph[1,2], B N'Kaoua[1], J Ruiz[2,3], A Simion[2], J M Mazaux[1,2], E Klinger[4]

[1]EA 4136 Handicap et Système Nerveux, Université de Bordeaux,
Rue Léo Saignat, Bordeaux, FRANCE

[2]SMPR Tastet Girard, CHU Bordeaux,
Place Amélie Raba-Léon, Bordeaux, FRANCE

[3]Institut de Formation en Ergothérapie, CHU Bordeaux
Rue Francisco Ferrer, Bordeaux, FRANCE

[4]Interaction Numériques Santé Handicap, ESIEA
Rue des Docteurs Calmette & Guérin Laval, FRANCE

[1]*eric.sorita@chu-bordeaux.fr*

ABSTRACT

Virtual Environments (VE) offer the opportunity to analyze the performance of people with Acquired Brain Injury (ABI) in Instrumental Activities of Daily Living (IADL). A number of studies have been carried out with the Virtual Action Planning Supermarket (VAP-S) among adult populations with cognitive disorders. Dysexecutive components such as planning have been identified from VAP-S outcome measures. The aim of this study is to explore the links between patients' performance, daily life integration and data from neuropsychological tests.50 adults with ABI in chronic stage (mean delay post onset = 54 ± 53 months) were recruited from a social and work integration program. A Principal Component Analysis (PCA) including a neuropsychological battery, the community integration questionnaire (CIQ) and performance in the VAP-S.The PCA raises four factors that explain 70% of the total variance. These factors show that the performance in the VAP-S cannot be only explained by executive functioning but dynamically mix high and low cognitive processes. Interesting questions also raise to know if performance in the VAP-S would only reflect cognitive disorders or conversely an adaptation level from preserved capacities. Functional performance in VAP-S virtual environment offers promising information on the impact of neuropsychological diseases in daily life. Executive functions impairment is showed. However other cognitive components are involved in VAP-S performance.

1. INTRODUCTION

Cognitive disorders have devastating consequences on functioning in daily living. According studies, they affect from 40 to 70% of the people with stroke (Godefroy et al, 2011) and causes long term integration problems for people with Traumatic Brain Injury (Le Gall et al, 2007)

In order to assess the impact of cognitive impairments in daily life functioning, virtual reality settings appear to be close to ecological assessments made in real life settings (Rizzo et al, 2004; Morganti et al, 2004). Environmental conditions can be better controlled and standardized while reliable indicators of behaviour can be recorded. So in using virtual environment settings two main concerns are raised: 1) What are the links between real and virtual performance for people with ABI? 2) What are the relationships between virtual functional performance and cognitive functioning?

The Virtual Action Planning Supermarket (VAP-S) simulates a medium sized supermarket which was designed for assessing and training individuals to plan and perform a shopping task (Marié et al, 2003; Klinger et al, 2004). It was used in several studies, by several teams, and for various populations. Moderate to high correlations were shown with subtests of executive functioning, notably planning, among various population with CVA, schizophrenia, MCI, Parkinson Disease (Klinger et al, 2006a; Josman et al, 2006, 2009, Werner et al, 2009). Klinger also showed that assessment with VAP-S was more sensitive in detecting cognitive impairment than the traditional neuropsychological tests (Klinger et al, 2006b). However the relationships between a comprehensive neuropsychological battery, functional performance in the task, and functioning in daily life have to be further explored.

2. METHOD

A retrospective study was conducted from data of patients with ABI, who attended a psycho-social program aiming to improve social and professional integration. For inclusion we only selected the records where all the data of the selected tests were recorded. Patients who had brain injury before the age of 16 years old were excluded. One record was also excluded because the patient presented visual impairment. Thus 50 patients were included in this study from the psycho-social program from 2009 to 2012. On the one hand we collected data from the neuropsychological evaluation (episodic memory, prospective memory, working memory index, perceptual organization index, processing speed, gonogo errors, divided attention omissions, visual scanning omissions) and global scores in the CIQ (Willer et al, 1993), a questionnaire that measures the level of independence in daily life. On the other hand we collected data from the VAP-S. Current clinical practice with the VAP-S follows a procedure that includes a time for familiarization. During this time that lasts less than 15 minutes, patients are trained to correctly perform the interactions within the virtual supermarket using the direction pad to move in the supermarket and the mouse to select items. This time is followed by the evaluation where the subjects have to purchase 7 items according to a shopping list. The virtual environment was projected onto a wall screen in a darkened room. The subjects were seated in front of a table on which were the keyboard and the mouse. To describe the performance of the patients in the virtual supermarket, four outcome measures from the VAP-S were selected for this study: number and duration of pauses, duration of move (which is the time subject moves to seek items) and the number of errors in selecting the shopping list items. An error is considered each time the subject selects an item that is different from the list or tries to select an item more than once. There was no time pressure for purchasing the items. If patients do not find the seven items, they can leave the supermarket after having paid or not the selected items. From the data described above, a Principal Component Analysis (PCA) was done.

3. RESULTS

Patients were relatively young (mean age: 34.96 ± 10.84), predominantly males (75%), and generally low-educated (mean level of education: 10.70 ± 2.18). The sample was mostly composed of people with Traumatic Brain Injury (TBI: 66% of the sample) and people with stroke (24% of the sample). Among the 50 patients, only two did not find the 7 items. One patient found 6/7 items and the second patients found 5/7 items before leaving the supermarket. The preliminary analysis showed that data were appropriate for PCA (Kaiser-Meyer-Olkin measure of sampling adequacy = 0.685; Bartlett's test of Sphericity, $\chi^2 = 491.471$; $p = .000$). The PCA raised a four factors model that accounted for 70 % of the total variance (table 1). Factor 1 links prospective memory, episodic memory, processing speed and perceptual organization to all the outcomes measures of performance in the VAP-S. This factor looks like an efficiency factor: the better cognitive efficiency was in these processes and the more efficient the performance was into the VAP-S. Factor 2 combines a level of efficiency in episodic memory with inhibition errors, and the total time of move and stops. Factor 3 combines the community integration, the global cognitive functioning, the divided attention and the visual scanning with the stops during functional performance in VAP-S. This factor appears to be related to a level of cognitive efficiency associated with a better level of integration in the community. Surprisingly an increase in the number and duration of stops in the performance is also observed in this factor related to this level of cognitive efficiency and community integration. Factor 4 combined inhibition errors, omissions in visual scanning and number of errors to select items. But in this factor the association of errors or omissions with a level of efficiency with working memory is difficult to interpret.

4. DISCUSSION

The primary aim of this study was to explore relationships that combine neuropsychological processes, a virtual daily task and level of community integration. The VAP-S confirms its sensitivity to cognitive impairment and to a lesser extent to community integration. It seems interesting to explore more deeply what kind of predictive relationships could be done between a virtual environment like the VAP-S and level of dependence in daily life. The PCA raises factors that combine low and high level of cognitive processes. These kind of combination could better reflect or be close to daily life functioning. But some combinations are difficult to interpret. For instance, factors 1 and 2 appear to show a significant role of episodic and prospective memory in order to do a shopping task using a shopping list. This links are highlighted in studies (Okahashi et al, 2013; Knight et al, 2006). In these studies memory impairment was clearly related to the number of time the subjects had to look at the shopping list. In these studies however subjects have to actively open the shopping list whereas in the VAP-S the shopping list is always displayed. Factor 2 is somewhat difficult to interpret. It combines a certain memory efficiency with impairment in inhibition and increase in duration of moving. Could it be a dysexecutive factor? Factor 3 shows an increase in the number and duration of stops. But this increase is rather associated with some levels of efficiency (in community integration, in a global cognitive efficiency, with less omissions in divided attention and visual scanning). Maybe, we can assume that the number and duration of stops may both reflect cognitive impairment but also conversely for some patients a better efficiency (or strategy) in searching for items? Factor 4 could also relate to an executive (behavioral) sub-factor? For instance Giovanetti et al. (2008) showed in using a naturalistic Test that commissions of errors were related to a specific impairment in executive functioning.

Table 1: *Component matrix.*

	Factor 1	Factor2	Factor3	Factor4
Community Integration Questionnaire (CIQ)	.200	.271	**.536**	-.193
CAMPROMPT	**.609**	.215	-4.5E-02	6.45E-02
WAIS-III, Perceptual Organization Index	**.450**	-.274	**.484**	.195
WAIS-III, Processing Speed	**.513**	-.175	**.490**	.252
WAIS-III, Working Memory Index	.354	-8.3E-02	**.588**	**.491**
Grober Buschke, third immediate free recall	**.669**	**.524**	-.176	-6.8E-02
Grober Buschke, third immediate cued recall	**.713**	**.536**	-8.9E-02	-1.2E-02
Grober Buschke, delayed free recall	**.727**	**.479**	-2.8E-02	-.102
Grober Buschke, delayed cued recall	**.718**	**.584**	-.120	-2.7E-02
Test of Attentional Performance Gonogo, errors	-.289	**.559**	-5.9E-02	**.566**
Test of Attentional Performance Divided attention, omissions	-2.0E-02	.249	**-.586**	-.253
Test of Attentional Performance Visual scanning, omissions	-.304	.323	**-.426**	**.546**
Number of pauses	**-.594**	**.559**	**.477**	-.193
Total duration of pauses (second)	**-.632**	**.568**	**.404**	-.194
Total duration of move (second)	**-.469**	**.694**	.335	-.171
Total number of errors of selection of items	**-.450**	.359	-.141	**.529**

Note : **Boldface indicates values >.400**

5. CONCLUSION

The use of virtual daily living tasks in a rehabilitation setting opens several perspective. VAP-S for instance could be used as a screening tool when there is a suspicion of cognitive impairments that could impact activities of daily living. Another asset that brings virtual reality in cognitive rehabilitation strategy is the ability to train the brain according to a global approach that is daily-life-oriented and not only discreet processes-centred.

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Color-check in stroke rehabilitation games

V Szücs, C Sik Lanyi, F Szabo, P Csuti

Department of Electrical Engineering and Information Systems, University of Pannonia,
Egyetem Str. 10., Veszprém, HUNGARY

szucs@virt.uni-pannon.hu, lanyi@almos.uni-pannon.hu, szabof@vision.uni-pannon.hu,
csutip@vision.uni-pannon.hu

www.virt.uni-pannon.hu

ABSTRACT

The article presents the colorimetric testing of rehabilitation games designed for the StrokeBack project. In this testing the main subject of the investigation was how the people with different colour-blindness types can percept the games. Many of the programmers and game designers do not pay attention to the aspect that the games should be accessible. This accessibility implies that the colour-blind users should be able to use the games the same way as the people with no vision problems.

1. INTRODUCTION

The purpose of the research showed in this article is to investigate the colours of the Virtual Reality (VR) based rehabilitation games (Sik Lányi, 2012a) designed for the StrokeBack (StrokeBack) project. The goal of the 'StrokeBack' project is to improve the speed and quality of stroke recovery by the development of a telemedicine system which supports ambulant rehabilitation at home settings for stroke patients with minimal human intervention. During our investigation we designed our VR based rehabilitation games in such a way that they would be enjoyable for colour-blind people as well.

The disorders in colour vision can be inherited and acquired. The cones' red and green colour specific paint cell's genes are linked to the X chromosome. Because of the sex-linked inheritance, there are 20 times more men involved. About 8% of Caucasian males and 0,4-0,5% of females are "red-green" colour-blind. The inherited blue-blindness (tritanopia) is much rarer, at only about 0,05% from the population can be detected. A part of the disorders of colour vision are not inherited, they are so called "acquired": several ophthalmological diseases can be followed by colour perception disorders (e.g. retinal diseases, glaucoma, cataracts, etc.) (Colour-blindness).

Stroke is a leading cause of death in the United States, killing nearly 130,000 Americans each year—that's 1 of every 19 deaths. Every year, about 95,000 people in the United States have a stroke. About 610,000 of these are first or new strokes; 185,000 are recurrent strokes.

Evidence from opticians is that about 10% of the male population are colour-blind. This together with stroke incidence rate refers to a statistically important problem.

2. THE STATE OF THE ART

The harmony of colours and proportions play an essential role in the appearance. Although many tend to neglect these issues, much scientific research is being conducted within this field. All this is based on the colour perception of the eye, which, however unconsciously, may have an influence on patients' decisions.

Scientists and artists of the last centuries (Itten, 1961), (Munsell, 1969), (Ostwald, 1969) and nowadays (Nemcsics, 1993), (Nemcsics, 2007) developed colour order systems where they defined rules to establish harmonic sets of colours. These colour harmony studies were based on the orderly arrangement of colours in the colour order system. The second group of authors (Goethe, 1810), (Chevreul, 1854) defined colour harmony as an interrelationship of colours. The main principles of these studies are "complementary" and "analogous" but these concepts are not consistent among the studies. Also, the colour wheel was often adopted as a tool to define these basic relationships. Other authors (Judd and Wyszecki, 1975) define colour harmony as a more universal concept: "when two or more colours seen in neighbouring areas produce a pleasing effect, they are said to produce colour harmony”. Also, there is no consistency among the principles and the keywords of colour harmony: It is *completeness* according to Goethe (Goethe, 1810), *order* according to (Nemcsics, 2007) and (Chevreul, 1854), and *balance* according to (Munsell, 1969). A quantitative model for two-colour combinations based on the CIECAM02 colour appearance model was developed by Szabó et al. (2010). Many other effects (i.e. age, cultural background) of colour harmony feeling has to be investigated in the future.

In visual experiences, harmony is something that is pleasing to the eye. It engages the viewer and it creates an inner sense of order, a balance in the visual experience. When something is not harmonious, it’s chaotic. At one extreme is a visual experience that is so bland that the viewer is not engaged. The human brain will reject under-stimulating information. The human brain rejects what it cannot organize, what it cannot understand. The visual task requires that we present a logical structure. Colour harmony delivers visual interest and a sense of order. Extreme unity leads to under-stimulation, extreme complexity leads to over-stimulation. Harmony is a dynamic equilibrium (Sik Lányi, 2012b).

Colour deficiency is often neglected, as most people do not consider colour deficiency as a serious problem. Up to 15% of the population being affected by one form or another of colour deficiency (Sik Lányi, 2012b).

It is quite common to see combinations of background and foreground colours that make web-pages, software, games etc. virtually unreadable for colour deficient users. Background, text, and graphics colours should be carefully chosen to allow understanding for people with colour deficiency. Designing for colour deficient people is complicated. It’s not a matter of green/red or yellow/blue combinations (Sik Lányi, 2012b).

The most important issue in designing for colour deficient users is not to rely on colour alone to convey information and not to use colour as a primary means to impart information (Karagol-Ayan, 2001).

3. THE METHODOLOGY USED

Currently 3 games are built in the StrokeBack project:

- Break the Bricks game: practices horizontal (right-left) wrist movements, (the player’s task is to control the object at the bottom of the monitor with this wrist movement)
- Birdie game: practices vertical (up-down) wrist movements, (the player’s task is to make a little bird fly and do not let it fall with this wrist movement)
- Gardener game: practices finger extension movements, (the player’s task is to pump a virtual sprinkler to make the plants grow by watering them)

These games can be used during the home rehabilitation process by the patients or replacing clinical rehabilitation and speeding up the process of recovery. These games are single player games, which the patient can play by himself/herself. It is expected that the patients will play more with the games, than they would do exercises.

To these games several ‘locations’ were developed:

- Break the Bricks: default bricks, car, cake, duck, ship, train
- Birdie: default meadow, cave (played with a bat), circus, forest, jungle, mountain, sea, town, winter
- Gardener: bluebell, carrot, currant, geranium, grape, pepper, rose, strawberry, tomato, tulip

Besides the 24 backgrounds for the 24 themes, more than 170 different objects had to be inserted, which had to be clearly visible. These were tested by different colour-blindness simulators and automatic testers.

Figure 1. shows two themes of Gardener as seen by a person with a good vision.

Figure 1. *Gardener’s “Bluebell” and “Grapes” themes as seen by a person with good vision*.

Figure 2 presents the jungle theme of game Birdie and the objects that can be inserted as obstacles in the theme.

Figure 2. *Jungle theme of "Birdie" game and the objects that can be inserted.*

4. THE RESEARCH & DEVELOPMENT WORK AND RESULTS

For the investigation 4 different colour-blindness simulators were used, which are accessible on the Internet and where pictures can be uploaded (ASP.NET), (ETRE), (Coblis) and a downloadable software, ColorOracle (ColorOracle), with which we could test the pictures appearing on the screen on the developer computer, to find out how the users of different types of colour-blindness: deuteranopia, protanopis, tritanopia; see the colours.

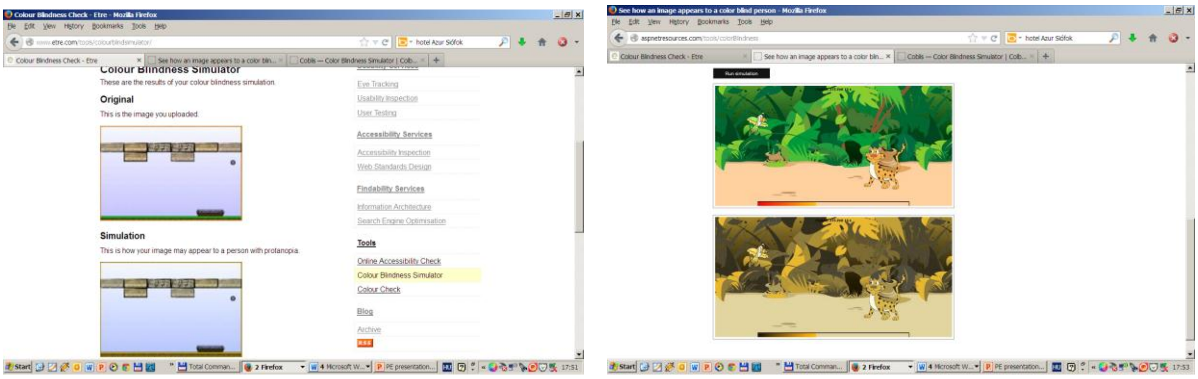

Figure 3. *Testing of "BTB basic brick" theme with ETRE simulator (left) and "Birdie jungle" theme with ASP.NET simulator (right).*

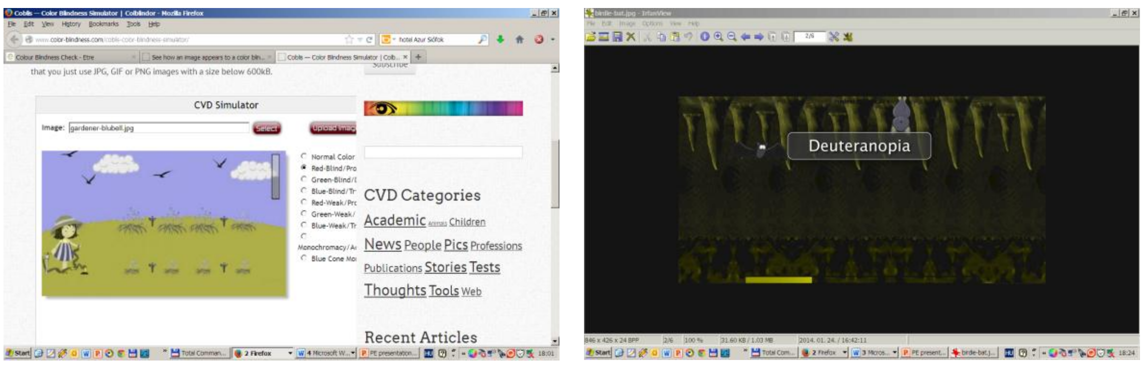

Figure 4. *Testing of "Gardener" with Coblis simulator (left) and "Birdie cave" theme with ColorOracle tester.*

4.1 Test and the contribution to the field

Testing has been completed not only with the *ETRE-*, *ASP.NET -*, *Coblis* – simulators and *ColorOracle* tester, but with Variantor's special glasses (variantor) with two individuals with good vision, and two colour-blind persons. Testing is really important because developers usually do not pay respect to colour-blind people.

We did not find any publications that would deal with the testing of colours of rehabilitation games. Unfortunately, the developers do not think about the colour-blind people. Thus, our case-study is of great importance.

5. CONCLUSION AND PLANNED ACTIVITES

As a result of our testing we reached to the conclusion that the objects are clearly visible, so the colour-blind patients can practice in the same way as the normal sighted. In the future the games will not only be tested with the software, but also with other simulation goggles (tunnel-vision, macula or lens degeneration). The clinical tests of efficiency (these refer to the colour test and efficiency of the rehabilitation too) are going to be from June, 2014. Our future plan is to test the games with more colour-blind patients as well.

At the conference the detailed results of testing – including the testing with simulation goggles – will be presented.

Acknowledgements: The StrokeBack research project is supported by the European Commission under the 7th Framework Programme through Call (part) identifier FP7-ICT-2011-7, grant agreement no: 288692.

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Challenges in developing new technologies for special needs education: a force-field analysis

P L Weiss[1], S V G Cobb[2], M Zancanaro[3]

[1]Dept. of Occupational Therapy and ICORE Learning in a NetworKed Society,
University of Haifa, Haifa, ISRAEL

[2]Human Factors Research Group, University of Nottingham,
University Park, Nottingham, UK

[3]FBK – Fondazione Bruno Kessler, ITALY

tamar@research.haifa.ac.uil, *sue.cobb@nottingham.ac.uk*, *zancana@fbk.eu*

ABSTRACT

Introduction of new technologies for use in special needs education requires careful design to ensure that their use is suitable for the intended users in the context of use and that learners benefit from the experience. This paper discusses issues that influence implementation of collaborative technologies designed to support learning of social communication skills in young people with autism. Taking a reflective view of lessons learned during the COSPATIAL project, a force-field analysis was applied to identify positive factors contributing to successful application development and negative factors that disrupted progress and implementation of the software. On the basis of our experience in the COSPATIAL project, recommendations for future projects are made.

1. INTRODUCTION

Autism Spectrum Conditions (ASC) affect behaviour and the ability to communicate and interact socially (Baily et al, 1996). Social competence, entailing a child's capacity to integrate behavioural, cognitive and affective skills in order to adapt flexibly to diverse social contexts and demands is one of the core skills that is impaired in children with High Functioning Autism. Social incompetence adversely affects a child's ability to learn in formal and informal educational settings, and to interact appropriately with other children (Bauminger, 2002). A variety of technologies have been used to train social competence of children with ASC. These include video modeling (Nikopoulos and Keenan, 2004), virtual reality (Parsons and Cobb, 2014), socially assistive robots (Dautenhahn and Werry, 2004) and multi-user or multi-touch tabletop surfaces (Giusti et al, 2011). To date, well-established practices for the design of technology to support therapeutic and educational interventions for these children are lacking (Davis et al, 2010).

A "Force Field" analysis is a framework for looking at the factors (forces) that influence the achievement of a designated objective and has recently been applied to the field of virtual reality for motor rehabilitation (Weiss et al, 2014). It identifies the positive forces that help an application to move towards achieving its goal (driving forces) and the negative forces causing it to become more distant from its goal (restraining forces). This paper presents a retrospective force-field analysis on COSPATIAL (http://cospatial.fbk.eu/) an EU-funded project whose goal was designing and creating collaborative technology applications to improve social competence of children with High Functioning Autism. The project investigated two categories of technologies for collaborative interaction: Collaborative Virtual Environments (CVE) and Shared Active Surfaces (SAS). Over a three year period, multidisciplinary design teams comprising technology developers, autism specialists, human factors researchers, teachers, and young people with autism located in three countries (Italy, Israel and UK) to develop software applications to support learning of social communication skills using each technology. 43 teachers from 8 schools and 85 children (48 typically developing and 37 with ASC) were involved in participatory design and evaluation of CVEs and a further 12 teachers from 5 schools and 24 children with ASC were involved in the formative SAS studies.

The analysis was based on examination of the accumulated evidence and lessons learned throughout the three-year project with the purpose to reflect upon the causes of specific design outcomes and generate recommendations for future technologies. Four major driving forces and four major restraining forces relating to the field of collaborative technology-based social competence training for children with ASC (as well as other related applications) were identified.

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2. DRIVING FORCES OF COLLABORATIVE TECHNOLOGIES

2.1 Affordances of collaborative technology

CVEs and SASs offer affordances that facilitate the design of collaborative activities. CVEs permit distributed synchronous communication, enabling children to talk directly to each other and work collaboratively but without physical proximity; SASs provide co-located, action-level collaboration (e.g., touching together). These technologies may be designed to empower teachers, allowing them to flexibly control the pace of a session; they can also empower children by enabling them to become actively involved in the educational activities.

2.2 Use of a strong theoretical model to inform design of learning tasks

COSPATIAL used the principles of Cognitive-Behavioural Therapy to inform the design of technology applications, and their intended mode of use with children. Although COSPATIAL adhered to CBT principles, our prototypes did not require a fully compliant CBT intervention model. Nevertheless, care was taken to abide by the model's tenets in order to remain consistent with its underlying assumptions as well as the evidence that supports its use.

2.3 User involvement in the design process

Co-design and participatory design are needed to develop prototypes that are likely to be more acceptable to target users, even if they sometimes present significant challenges (due to constraints related to time, effort and technical complexity). It is crucial to implement the process in a manner that ensures sufficient time to involve all stakeholders so that they can achieve a comprehensive understanding of the applications and can learn to interact with each other. Since participatory design processes are not always feasible, different levels of feedback from users may need to be elicited. In addition, it is important to recognize the challenge of the design process when co-designing with a group of people with different backgrounds, levels of involvement, geographical locations.

2.4 Personalisation of educational technology

There is a strong need for teachers and therapists to be able to personalize technology tools. There will be less chance of adoption of a given technology if the design process produces a tool that is too specific to the original design objective (e.g., only social collaboration) or does not enable sufficient variations in levels of ability or styles of practice. Embracing a tactic of personalization will ensure a much wider usage in terms of educational objectives, target problems and the age and abilities of the children. Although personalization should aim to adapt features of the tool to meet a child's skills, it should also provide a truly flexible tool for the teachers to custom-build learning experiences.

3. RESTRAINING FORCES OF COLLABORATIVE TECHNOLOGIES

3.1 Cumbersome and/or expensive technologies

Technologies (particularly large tabletops or complex virtual reality systems) may be too cumbersome and expensive for daily use. This will likely limit and even impede their implementation in the school system. In educational frameworks that are dedicated specifically to children with ASC, the purchase and installation of specialized equipment and software may be feasible. However, in settings where mainstreaming is provided via special classes for children with ASC, the use of cumbersome equipment is less feasible. It is necessary to continue to explore lost-cost, low-encumbrance platforms to deploy the prototypes. For example. use of the multi-mice version of two of the COSPATIAL SAS applications that had originally been designed for a multi-touch tabletop (Weiss et al, 2011) and COSPATIAL CVEs Block Challenge and Talk2U running on standard laptops (Cobb et al, 2014). Educational software must take into account requirements related to the context of use (e.g., a classroom); constraints (e.g., cost, size) should be identified at an early development stage. Nevertheless, in the context of COSPATIAL the possibility of experimenting with expensive and cutting-edge devices allowed us to identify and explore patterns of use (i.e., constraining the interaction via multiple, simultaneous actions) that were then scaled down to more affordable solutions (e.g., multi-mice approach).

3.2 Need for on-site instruction and support in technology usage

Despite widespread positive expression of interest in using collaborative technologies on the part of teachers, clinicians and parents, actual usage will only take place with on-going, on-site instruction and support. It is necessary to accompany the transition between research efforts (such as the COSPATIAL project) and actual use in everyday practice by means of projects that are more oriented toward development of learning resources and best-practices. It is necessary to identify constraints within the special education sector for children with ASC that facilitate the adoption of technology. For example, adoption of cumbersome systems in mainstream schools will be more difficult than in specialised schools or after-school centres. Successful adoption of technology will be more likely if they are tailored to the constraints of the setting in which they will be used. In planning the transition from a research prototype to a system actually used in real settings, the robustness of the software itself is not enough. Deploying the technology depends on maintenance and support which can only be assured by a commercial company. Such involvement need not happen from the outset; indeed, not having to satisfy the interests of specific companies gave COSPATIAL greater flexibility in exploring different platforms without being committed at too early a stage. However, commercial support for full exploitation is essential.

3.3 False expectations and misunderstandings during the design process

Although participatory design is a potentially effective approach for creating collaborative technologies, care must be taken throughout the entire process in order to avoid false expectations which can impede any positive effect. Thus, co-design must be implemented with emphasis on communication and clarification, especially when the teams are geographically distributed and have different backgrounds and languages. The judicious use of tools to trace decision-making and concept clarification help track when and why decisions are taken. In the case of ASC, including children in the design process is problematic because of their difficulties with Theory Of Mind (understanding what the others think). Although rapid prototyping is often suggested as a remedy to enhance visualisation of the proposed design, the notion of "rapid" is very subjective; it may be too long relative to the overall length of the project where evaluation cannot commence until the software is more advanced.

3.4 Insufficient evidence-based practice

The lack of conditions that favour optimal research designs holds back progress by reducing the impact of a technology's results. Formative studies should be initially favoured in design-oriented projects especially when the duration is limited to three years and less. However, it is essential to fund longer-term intervention studies in order to achieve a solid base of evidence for the practice of novel technology applications. The experience with COSPATIAL is that the scientific community (both in the field of autism and in the field of human-computer interaction) is keen to accept results of small studies and these forums may help to fund the type of pilot and single case study design research that will lead to the funding of full, evidence-based research designs.

4. RECOMMENDATIONS

The difficulties experienced by COSPATIAL in aiming to both develop and evaluate software prototypes is not unique to autism research. Although a project evaluation plan needs to be realistic and adaptable during its lifecycle, it can be difficult to anticipate problematic issues when working with new design teams to develop novel applications that have not previously been used in an educational setting. Retrospective use of the force-field analysis of the COSPATIAL project enabled us to identify positive and negative factors that influenced project progress and outcome. On the basis of this reflective review, a number of recommendations are suggested that may facilitate future development of educational software using new technologies, intended both for special needs and mainstream educational contexts:

- *Establish a core design team representing key stakeholder groups*. The use of a co-/participatory design is not a trivial undertaking. In order to fully take advantage of this approach, it should be seriously applied from the beginning of the project by using appropriate methodological approaches (which may differ for individual users or groups of users) and explicitly controlling the process. The participation of all the stakeholders is fundamental but we have learned the presence of a core team of experts that helps to liaise with the core users (teachers and children) is essential.
- *Include all stakeholders in the design process*. Input from the target users (in this case children with high functioning ASC together with teachers/therapists) was vital for promoting greater acceptance of the developed software. Thus, co-/participatory design should be employed in projects even if the target population has significant disabilities. Children with ASC can be included in the participatory design process, although it is necessary to adapt the activities to suit their unique characteristics as well as their individual needs (Millen et al, 2012). Moreover, there should be appropriate expertise represented within the research team to enable such participatory design processes to take place.
- *Do not assume shared understanding between design partners*. In any multi-disciplinary co-design team, it is essential to manage the interactions and the expectations, to be clear about the goals and the procedures, to negotiate the level of participation and the different responsibilities of the people involved and to effectively, but precisely, trace the decisions taken during the process.
- *Base learning task design on learning theory but do not be afraid to apply 'cautious flexibility' and adapt it to suit user needs*. CBT proved to be an effective theoretical framework to guide the design of the

prototypes by providing a context to conceptualise the affordances offered by the CVE and SAS prototypes and to explore the advantages and limitations of those affordances in meeting the requirements of the CBT principles (e.g., dividing the session into two interleaved parts for learning (cognition) and experiencing (behaviour). The CBT model also provided us with specific techniques and procedures, such as concept clarification and role-playing.

- *Conduct technology development and testing in the context of use.* Implementation of new technology on the classroom or other learning environment beyond the lifetime of the project is more likely to be successful if all considerations relating to the context of use have been properly taken into account. Setting up demonstrations of pre-configured technology developed in the research lab is not sufficient; the equipment must be set up and used by teachers and other stakeholders in situ.
- *Utilise affordances of the technology that directly address core learning needs*. The cost and inconvenience of using new technologies in education will be worthwhile if the added value to students is evident. Exploiting the affordances of CVE and SAS related to their inherent collaboration dimensions for tasks directly related to the core diagnostic difficulties of autism, offers learning tools that may not be available through other means and, in COSPATIAL, led to additional applications for other children with special needs.

Acknowledgements: COSPATIAL (2009-2012) was funded under the Seventh Framework Programme of theEuropean Commission (http://cospatial.fbk.eu/). We thank our project partners and also thank the students and teachers of our collaborating schools in the UK and Israel.

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Self-management intervention for amputees in a virtual world environment

S L Winkler[1], R Cooper[2], K Kraiger[3], A Ludwig[4], A Krueger[5], I Gaunaurd[6], A Fisher[7], J Kairalla[8], S Elliott[9], S Wilson[10], A Esquenazi[11]

[1, 10]Occupational Therapy Department, [2]Conflict Analysis and Resolution Department, Nova Southeastern University, Ft. Lauderdale, FL, USA

[1,6]Miami Department of Veterans Affairs Medical Center, Miami, FL, USA

[3]Psychology Department, Colorado State University, Fort Collins, CO, USA

[4,5]Virtual Ability, Inc., Aurora, CO, USA

[7]US Army Telemedicine & Advanced Technology Research Center (TATRC) Fort Detrick, MD, USA

[8]College of Public Health and Health Professions and College of Medicine, University of Florida Gainesville, FL, USA

[9]Scott Elliott e-learning Solutions, Chicago, IL, USA

[11]MossRehab Einstein Healthcare Network, Philadelphia, PA, USA

[1]swinkler1@nova.edu, [1]sandra.winkler@va.gov, [2]robicoop@nova.edu, [3]kurt.kraiger@colostate.edu, [4]emecapalini@gmail.com, [5]akrueger@virtualability.org, [6]ignacio.gaunaurd@va.gov, [7]ashley.g.fisher.civ@mail.mil, [8]johnkair@ufl.edu, [9]scott.t.elliott@gmail.com, [10]sw1269@nova.edu, [11]aesquena@einstein.edu

[1]www.virtualhealthadventures.org, [4,5]www.virtualability.org

ABSTRACT

An e-learning self-management intervention for amputees was created then beta-tested for usability using focus groups and qualitative analyses. The next phase of the study compares change in outcomes when the intervention is presented in e-learning and virtual world conditions. Focus group results identified the self-directed structure and video presentation aspects of the intervention as strengths and were less enthusiastic about use of text. Research team experiences, beta test results, and available technology suggest the need to rethink traditional learning theory in order to meet the needs of the modern learner and create more modern learning environments.

1. INTRODUCTION

1.1 The Problem

Amputation is a life-long condition. Although acquiring current and evolving prosthetic- and health-related information will be an on-going process throughout the lifespan of the amputee, amputees report a lack of information available on new prosthetic devices (Berke et al, 2010). We hypothesize that amputees who feel well-educated about their prosthesis care are more likely to adhere to treatment recommendations and have improved health outcomes.

1.2 The Approach

This project uses a self-management approach to build an intervention that provides evidence-based health information for amputees. The effectiveness of self-management programs is attributed to enhanced self-efficacy. The approach is based on Bandura's social cognitive and self-efficacy theories where evidence-based knowledge of risks and benefits creates a pre-condition for change, but must be coupled with a self-influence, e.g., self-efficacy or belief, before desired physical, social, and emotional outcomes can be achieved, or knowledge translated into action (Bandura, 2004).

Bandura's four sources of self-efficacy were used to guide the development of this intervention: performance accomplishment/mastery, modeling/vicarious experience, verbal persuasion/interpretation of symptoms, and social persuasion (Bandura, 2004). The five core skills of self-efficacy identified by Lorig and Holman (2003) were also taken into consideration: problem solving, decision-making, resource utilization, forming a patient/health care provider partnership, and taking action. While Bandura's theories guided the nature of the content, Kraiger's Decision-Based Evaluation Model (Kraiger, 2002; Kraiger et al, 1993) guided the presentation of the content. Kraiger's model posits that learning in training consists of affective (self-efficacy), cognitive, and behavioral change. Using Kraiger's model, we provided declarative knowledge to facilitate cognitive change and procedural knowledge to facilitate the potential for behavioral change.

1.3 The Context

A limitation of the more traditional mass communication of health information is that it is not individualized; yet individualization, social support, and guidance impact the success of health programs (Bandura, 2004). Few studies have tested the effectiveness of using a virtual world environment to disseminate evidence-based information while at the same time building self-management skills. Virtual world environments such as Second Life® (SL) have been used to enhance patient experiences and increase engagement in their healthcare (Cantrel et al, 2010; Hoch et al, 2012; Johnson et al, 2014). Virtual worlds allow users to "explore, create, imagine, collaborate, role play, interact, socialize, learn, and experience events in a safe and vivid manner" (Ghanbarzadeh et al, 2014). A transfer of behavior from a virtual world to the real world has been documented (Bayraktar and Amca, 2012; Fox and Bailenson, 2009; Napolitano et al, 2013).

1.4 The Purpose

The purpose of our three-year project is test the effectiveness of delivering evidence-based health information to amputees in a virtual world environment. Specifically, delivery in the Second Life (SL) virtual world and e-learning environments will be compared on the following outcomes: use of prosthetic devices, self-efficacy, psychosocial status, pain interference, and function.

This presentation will describe the project and provide results of the beta testing of the self-management intervention that will be used to refine the intervention prior to the randomized clinical trial that will begin in June of 2014.

2. METHODS

2.1 Intervention

The self-management intervention was created by the research team over a one-year period using Microsoft PowerPoint. The intervention was organized into four sections: History of Prosthetics Epidemiology of Amputation, Phases of Rehabilitation (Esquenazi, 2004), and Current Technology. The history, epidemiology, and current technology sections were declarative knowledge based, that is, learners are expected to be able to recognize or recall propositional knowledge or new information presented during training. The phases of rehabilitation section included declarative and procedural knowledge. For the latter, learners are expected to apply rules or implement procedures covered in training. Once the research team had reviewed and edited each section as a group, the PowerPoint was converted to an e-learning course using Articulate software (www.articulate.com), which will serve as the control in the randomized clinical trial. Simultaneously, a virtual world version of the intervention was created in the SL virtual world by Virtual Ability, Inc. Figures 1, 2, and 3 compare constructs presented in real life (e-learning) with those in Second Life.

2.2 Participants and Data Collection

Beta-test subjects were recruited using convenience sampling. Four women and five men participated, including six occupational and physical therapy clinicians who were colleagues of members of the research team with expertise in treating amputees and three amputees who were also the three amputee actors in the training videos. Following signing of informed consent, the beta testers accessed the e-learning version* of the intervention via links on the project website (www.virtualhealthadventures.org). The focus groups were held online using Adobe Connect software and were conducted as audio interviews supported by synchronous chat. The interview questions were organized around three main topic areas: overall impressions, style and format of the intervention, and the content of the intervention. Questions were open-ended to elicit descriptive, detailed responses. Data was collected through in-depth notes taken during the focus group interviews, as well as via digital recording. Following the interviews, the recordings were played back and additional notes were taken to capture all relevant content of the interviews as well as direct quotes illustrative of the subjects' feedback.

**Due to the nature of the research questions and timeline and resource constraints, beta testing was done on a development server using only the e-learning format.*

Figure 1. *History of prosthetics in the e-learning and SL environments.*

Figure 2. *Stair training in the e-learning and SL environments.*

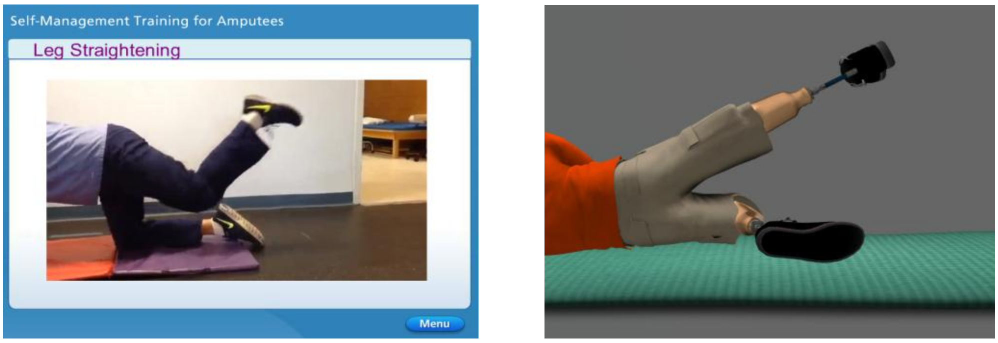

Figure 3. *Conditioning exercises in the e-learning and SL environments.*

2.3 Analysis

Qualitative content analysis was used to analyse the complete set of detailed interview notes. Descriptive coding was used to highlight the experiences and perceptions of the beta-test subjects, followed by pattern coding to identify key themes emerging across the focus group interviews. These findings were summarized in a report which included quotes as exemplars of the key points shared by the subjects.

3. RESULTS

Data were analysed by summarizing common points from all three focus groups. The common points from all three focus groups are presented here.

1. Overall Impression. The self-directed structure of the intervention was highly regarded. The navigation could be clarified. All web links should be active.
2. Style and Format. Subjects reported the sections were visually pleasing but some slides included too much textual information. The videos received universal acclaim.
3. Content. Subjects reported the information was accurate and would be useful to new amputees. Several subjects felt there was too much historical information while at least one subject valued the depth of the historical information. Subjects recommended a section that targeted family members.

4. DISCUSSION

This study evaluated the overall impression, style and format, and context of a self-management intervention in order to improve the intervention prior to its use in a randomized clinical trial. The purpose of the randomized clinical trial, which will begin during summer 2014, is to compare patient-level outcomes (dependent variable) when the intervention is delivered in either an e-learning or a virtual world environment (independent variable).

Beta-test subjects expressed high regard for the self-advocacy approach, which is characteristic of the self-management approach. The subjects praised the videos (procedural knowledge) with less appreciation of the text (declarative knowledge). Perhaps the declarative knowledge was not appreciated because the beta-test subjects were already either clinical experts or well-adjusted amputees; subjects did comment that this would be useful information for new amputees. Because our focus group members were already experts, beyond the need for facts, they were ready to experience the more novel procedural knowledge aspects of our project. Alternatively, it is possible that text has become boring to some learners. Because of these findings, we have added the following instructions to the randomized portion of the clinical trial: "Sections can be completed in any order. Not all sections need to be completed." We can then use Internet tracking mechanisms to examine the order in which users view sections, which sections were viewed most often, and how long each section was viewed.

In summary, subjects indicated a preference for a more modern learning environment. For example, less text and more videos were desired. Research team experiences and beta test results have prompted this research team to rethink how and when to mix declarative and procedural knowledge to meet the needs of the modern learner.

Acknowledgements: This project is supported by Agency for Healthcare Research and Quality Grant # R1R24HS022021, PI Sandra Winkler, 2013-2016.

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Grid-pattern indicating interface for ambient assisted living

G Yamamoto[1], Z Asghar[2], Y Uranishi[3], T Taketomi[4], C Sandor[5], T Kuroda[6], P Pulli[7], H Kato[8]

[1,2,4,5,8]Graduate School of Information Science, Nara Institute of Science Technology,
8916-5 Takayama, Ikoma Nara, JAPAN

[2,7]Department of Information Processing Science, University of Oulu,
90014, Oulu, FINLAND

[3,6]Kyoto University Hospital, Kyoto University,
54 Shogoin Kawahara-cho, Sakyo-ku, Kyoto, JAPAN

[1,2,4,5,8]*{goshiro, zeeshan-a, takafumi-t, sandor, kato}@is.naist.jp*,
[7]*petri.pulli@oulu.fi*, [3,6]*{uranishi, tomo}@kuhp.kyoto-u.ac.jp*

[1,2,4,5,8]*imd.naist.jp/index_e.html*, [2,7]*www.oulu.fi/english/*, [3,6]*www.kuhp.kyoto-u.ac.jp/~mi/en/*

ABSTRACT

We propose a grid-pattern indicating interface to provide instructions remotely from remote site to support independent daily life of senior citizens. Our aim is to realize smooth and easy telecommunication between supported senior citizens at local site and supporting caregivers who are in remote site. Although we have used a monitoring method with video streaming where the remote caregivers indicate work steps as a conventional way, occlusion and depth perception problem was occurred. Our method that provides grid-pattern interface to remote caregivers could be a solution for the problems by indicating the spatial instruction easily on 2D input interface. Our prototype has been implemented with a colour camera, a range image sensor, and projector.

1. INTRODUCTION

Most countries are facing serious situations nowadays, and one of them is super-aging society. It is estimated by the year of 2050 in Finland and Japan, the amount of people over the age of 65 will cover 27% and 33% of the total population, respectively. The number of senior citizens who suffer from varying memory impairments is also going to get doubled during the next 30 years (Ferri et al, 2006). The increase of senior population requires more caregivers inevitably. However, most of caregivers have already reported physical and mental problems (Schulz et al, 1990; Rabins et al, 1982). We need to consider the balance between the supporting generation and the supported generation, and avoid from making negative feedback loops by increasing heavily supported persons. On the other hand, most of the persons who have mild cognitive impairment persons just need small help to avoid from getting bad in memory. One of our goals is to realize the ambient assisted living environment that allows 5 to 10 caregivers support 10 to 30 senior citizens remotely via the Internet connection. In this paper, we propose a grid-pattern indicating interface because an easy instruction system would be required to make burdens of caregivers as less as possible.

We focus on a kitchen workspace because cooking is an important part of daily life. Our method is to utilize the combination of a camera and a projector, to provide visual information as guidance or as a set of instructions onto the physical surface as Molyneaux et al. has proposed (2007). Ju et al. (2001), Bonanni et al. (2004), and Sato et al. (2014) had applied the projection technology to kitchen workspace for supporting cooking. On the other hand, the research about the remote collaboration has been often done as references (Kuzuoka, 1992; Sakata, 2003) show. We also are challenging to create a remote collaboration situation in kitchen and especially pay attention to how easily the remote caregiver better provides instructions to a senior citizen at the local site. In this paper, we propose grid-pattern interface for the remote caregivers to indicate points in the space at the local site a solution.

2. METHOD

We propose a grid-pattern indicating interface for remote caregivers to assist local persons remotely. The whole system consists of two sites: a local site where assisted persons are and a remote site where caregivers are.

Figure 1 (a) shows the overview of our conceptual system. Remote site has remote monitoring view and grid interface on the computer screen. At the local site at a kitchen workspace, a camera, a range image sensor, and a projector are installed. The camera captures a scene from the workspace including the objects and the surfaces. In order to realize our system, we need to calibrate geometrical relations between each device as shown in Figure 1 (b). Using the result of the calibration, we can keep the correspondence between grid-pattern interface view and real workspace.

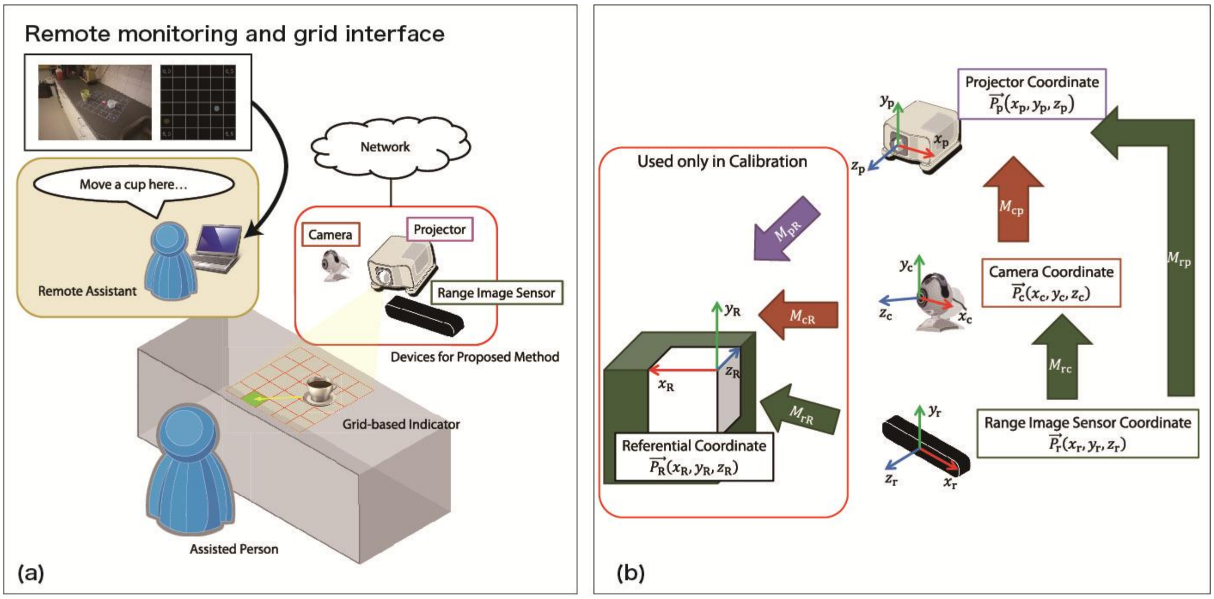

Figure 1. *Our conceptual system and coordinate systems of the devices. (a) Remote caregiver can monitor local site remotely with grid-pattern indicating interface via the Internet. (b) Geometrical relations between each device need to be calibrated in advance.*

2.1 System Calibration

There are three coordinate systems: a camera coordinate system, a range image sensor coordinate system, and a projector coordinate system as shown in Figure 1 (b). We can know the geometric relationship with the colour in the target scene by calculating each transformation matrix between each coordinate system in advance. The transformation matrices can be obtained by using a referential coordinate system.

First, transformation matrix between the range image coordinate system and the referential coordinate system is estimated. The range image sensor captures the scene with the referential object as range data, then three plane surfaces on the referential object are detected. The three normal vectors corresponding to the three plane surfaces are used as basis vectors, and in the referential object coordinate system the intersection of three plane surfaces is used as the origin.

Second, we can estimate transformation matrices corresponding to the color camera and the projector by applying Gray code pattern projection (Sato, 1985). The basis vectors and the origin of the referential object that is represented in the camera or projector coordinate system are estimated according to measured geometry of the scene which includes the referential object.

As the last step in main calibration process, we need to compute transformation matrices between each device. For example, the transformation matrix M_{rc} is computed by simple multiplication of $M_{rc} = M_{Rc} M_{rR}$, where $M_{Rc} = M_{cR}^{-1}$.

Only the relative positions between the devices should be maintained in use. In other words, a simultaneous movement of the devices is allowed. It indicates that the system can be moved freely if the devices are fixed in a their locations.

2.2 Target Surface Estimation and Object Locating

There are mainly two steps, which are estimation of a parameter of the target planar for fixing the grid-pattern area in the workspace and visualizing a position and a color of the target objects on the grid-pattern view for the remote caregivers.

First, we estimate the dominant plane from the range image that has a certain color. The color of each pixel in the range image is given from the converted camera image via M_{cr}, where $M_{cr} = M_{rc}^{-1}$. Second, the pixels extracted as the target planar surface are clustered according to the distance between each point. Finally, each cluster is projected onto the two dimensional coordinate system of the target planar surface after the center of gravity has been calculated. Then the average color and the position of each cluster are shown on the grid-pattern view.

2.3 Grid Pattern Indication

We assume a situation where a remote caregiver gives some instructions to a senior citizen at his/her home. When the caregiver gives instructions, communication with spatial information where the remote caregiver indicates for the senior citizen is important. In conventional way, the remote caregiver monitors the senior with video streaming and indicates a location by speaking or clicking on the monitoring view. The monitoring makes it easier to understand in terms of spatial information. Nevertheless there is still the remaining problem of occlusion and depth perception, which causes mistakes in a remote caregiver's judgments.

A grid-pattern indicating view for a remote caregiver is one possible solution that can avoid from occlusion and depth perception problems.

3. IMPLEMENTATION

We implemented a prototype system as shown in Figure 2. The camera was being used a Logitech C910 which captures images in 640x480 pixels. The range image sensor was a Microsoft Kinect for Windows which obtains range images in 320x240 pixels. The projector was an Optoma EP1691i Digital Light Processing Projector which shows an image in 1280x768 pixels onto a physical surface. Additionally, we applied Point Cloud Library 1.5.1, OpenCV 2.4.0, and Microsoft Kinect for Windows 1.5 to our prototype system.

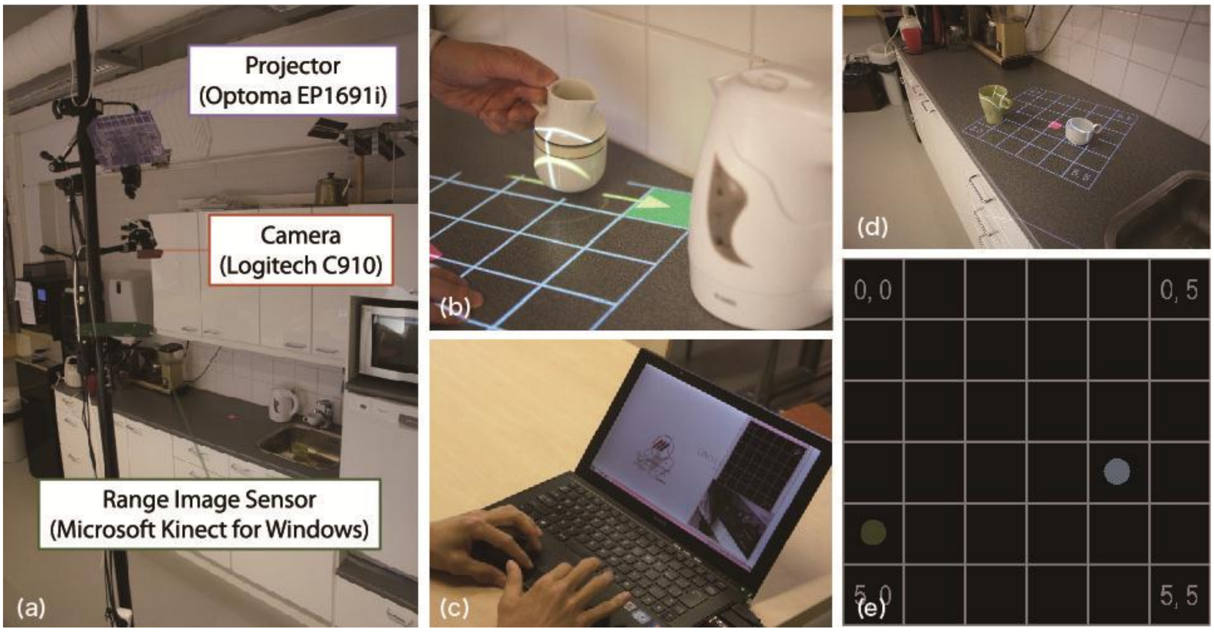

Figure 2. *Our prototype system: (a) overview of the prototype system that mainly consists of a colour camera, a range image sensor, and a projector on the pole to project visual instructing information onto the kitchen workspace, (b) the scene of local site with projected lights, (c) the scene of remote site with grid-pattern indicating interface on a computer screen, (d)(e) the view of local site and the grid-pattern interface, respectively, that are shown on the computer to the caregivers at the remote site.*

We demonstrated the implemented system with several test users briefly. As a result of our observation, most of the users whom were remote caregivers could indicate where he/she wanted to indicate in the space of the local site. However, we did not confirm how precise they could indicate with the grid-pattern interface. On the other hand, visualizing the projected grid-pattern onto the local site would not be really needed for the senior citizen to understand where the remote caregiver indicates. Projection with infrared lights could be a method to make invisible and visible grid-patterns on the target surface simultaneously for the local and the remote person, respectively.

4. CONCLUSION

We have proposed a grid-pattern indicating interface for remote caregivers in ambient assisted living. Our method was implemented by installing a colour camera, a range image sensor, and a projector on the local site. The grid interface could have correspondence to the real workspace of the local site with calibration between each device. Finally, we briefly confirmed how the implemented prototype operated while the test users indicating remotely.

Future work includes a user test to confirm the accuracy or easiness of our method, making the available workspace bigger, and improving object recognition for representing the real situation into the grid-pattern interface.

Acknowledgements: This research work is partly supported by AF-JST as the Japan-Finland Research Cooperative Program.

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