Proceedings of the 3rd international conference on disability, virtual reality and associated technologies (ICDVRAT 2000)

The 3rd International Conference on

Disability, Virtual Reality and Associated Technologies

Proceedings

Edited by:

Paul Sharkey (Programme Chair)
Antonio Cesarani (Conference Co-Chair)
Luigi Pugnetti (Conference Co-Chair)
Albert Rizzo (Conference Co-Chair)

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ICDVRAT 2000

Proceedings:

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Introduction

The purpose of the 3rd International Conference on Disability, Virtual Reality and Associated Technologies (ICDVRAT 2000) 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. The initial Call for Papers generated considerable interest, with high-quality contributions from researchers in across 16 countries, many from beyond Europe.

The International Programme Committee have selected 42 papers for presentation at the conference, collected into 11 plenary sessions: Enhancing Mobility I & II; Interfacing to Virtual Environments I & II; Acoustic Virtual Environments; Education & Community Access; Training Environments; Virtual Environments & Autism; Assessment & Rehabilitation; Design of Virtual Environments; and Cognition. The conference will be held over two days at the Hotel Carlos V, in the town of Alghero, Sardinia. We are pleased to include an essay on the region by Professor Al Rosa, which details some of the interesting history and customs of the area.

ICDVRAT 2000 follows on from the success and of the first two conferences, held in Maidenhead, UK in 1996 and Skövde, Sweden in 1998. Originally titled the *'European Conference Series ...'*, the change to *'International'* was adopted to more accurately reflect the origins of many contributors and delegates in previous years. Abstracts from this conference and from the two previous conferences are available online from the conference web site *www.cyber.reading.ac.uk/icdvrat/* as are most full papers from 1996.

International Journal of Virtual Reality

As in 1998, the Proceedings of ICDVRAT 2000 will be published in full on the CDROM issued with a forthcoming Special Issue of the International Journal of Virtual Reality dedicated to the conference. Selected papers concentrating on mainly technological aspects will appear in the print version of IJVR Special Issue. All papers from ECDVRAT '98, with additional multi-media material, are published in IJVR 4-1, available from *www.ijvr.com.*

CyberPsychology & Behavior

We are pleased to announce that a Special Issue of the journal CyberPsychology & Behavior will be devoted to ICDVRAT 2000, and will include selected papers concentrating on psychological issues.

Acknowledgements

The Conference Chairs would like to thank the Programme Committee, for their input to the conference format and focus, and for their commitment to the review process, the authors of all the papers submitted to the conference, the Organisation Committee, and the students who help out over the period of the conference. On behalf of ICDVRAT 2000, we welcome all delegates to the Conference and sincerely hope that delegates find the conference to be of great interest.

The Conference Chairs for ICDVRAT welcome any feedback on this year's conference. We would also welcome suggestions for the venue/host country for ICDVRAT 2002.

Paul Sharkey, Antonio Cesarani, Luigi Pugnetti, Albert Rizzo

Conference Sponsors

The principal sponsors of ICDVRAT 2000 are the Institution of Electrical Engineers, the International Journal of Virtual Reality, the Department of Cybernetics, of the University of Reading, the Fondazione Don Gnocchi and the Universidà di Sassari.

Additional help in publicising the conference has been gratefully received from vrpsych-l@usc.edu, uk-vrsig@mailbase.ac.uk, and Ability Magazine, amongst many others.

Artwork

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Abstracts

In alphabetical order, based on first author.

Collaborative networked framework for the rehabilitation of children with Down's Syndrome, **Ana Margarida Almeida** and **Fernando Ramos**, University of Aveiro, PORTUGAL

This paper describes a reference architecture to support a multi-user virtual communication platform that enables rehabilitation and social integration of Down's Syndrome children. The platform, based on an on-line virtual collaborative environment supported by the World Wide Web, includes collaboration and interpersonal communication devices and data collection mechanisms to provide management information for system and effectiveness evaluation. It allows children with Down's Syndrome, geographically spread in schools and homes, to access a distributed virtual platform able to offer communication and shared construction processes. This will leverage the exploitation and development of communication and socialisation abilities, creating conditions to the exploitation of new rehabilitation patterns.

Preventing mobility-related accidents in elderly and disabled, **Dario Alpini, Antonio Cesarani, Luigi Pugnetti, Laura Mendozzi, Roldano Cardini, Reuven Kohen-Raz, Ales Hahan** and **Guiseppe Sambataro**, Don Gnocchi Foundation/University of Sassari/University Of Milan San Paolo Hospital, ITALY/Hebrew University Of Jerusalem, Jerusalem, ISRAEL/University of Prague, CZECH REPUBLIC

As the elderly and mobility-disabled populations in European countries continue to increase, it is imperative that mobility-related accidents and associated consequences be prevented whenever possible. This multi-modal project is aimed to provide educational, diagnostic and VR rehabilitative approach to prevention of falls in aging.

Applications of virtual reality for the assessment and treatment of topographical disorientation: a project, **Laura Bertella, Stefano Marchi** and **Giuseppe Riva**, Istituto Auxologico Italiano/Università Cattolica del Sacro Cuore – Milano, ITALY

The traditional tools afforded by neuropsychology have proved to be of considerable service not only for the description of the clinical course of illnesses, but also for their nosographic and diagnostic contextualization. Virtual reality technology appears to be able to take on a valued rôle within the variety of diagnostic tools that are necessary for an adequate assessment of impairments of executive function. Development of diagnostic tools based on virtual reality may be cost-effective, particularly with respect to old but still widely used paper-and-pencil tests. The aim of the project presented in this paper is the creation and validation of various VEs to improve the assessment and rehabilitation of topographical disorientation, a disease present in various cerebral pathologies.

Computerised system to improve voluntary control of balance in neurological patients, **Davide Cattaneo** and **Roldano Cardini,** Don Gnocchi Foundation, ITALY

The treatment of acquired impairments of balance is one of the most elusive problems rehabilitative medicine is facing. Computerized systems to measure how patients control their balance in static conditions have been introduced long ago into clinical practice and proved to be useful; we have designed and developed a computerized system called "BioGP" which combines features of a classic stabilometric platform with those of a retraining device based on visual feedback The aim of this study was to identify homogeneous groups of patients and to provide objective proof of effectiveness for the rehabilitation of patients with balance disorders. The findings confirm that the new equipment provides clinically valid and sensitive information concerning subjects' ability to control voluntary shifts of COP while standing. The information is relevant to VR applications using basically the same approach and are encouraging for possible use of the system as a rehabilitation instrument.

Employing virtual reality for aiding the organisation of autistic children behaviour in everyday tasks, **Dimitrios Charitos, Georgios Karadanos, Ekaterini Sereti, Stathis Triantafillou, Sofia Koukouvinou and Drakoulis Martakos**, University of Athens, GREECE

This paper documents part of a research project under the title: "Computer-Assisted Education and Communication of Individuals with Autistic Syndrome", which aims at designing and developing computer-based environments for aiding the education and assessment of autistic children. The theoretical basis of the project is explained. Finally, a scenario titled "Returning Home" for a virtual reality application, which would aid educators in organising the behaviour of autistic children in a series of everyday activities, is described.

Virtual city for cognitive rehabilitation, **Rosa Maria Moreira da Costa, Luís Alfredo Vidal de Carvalho** and **Doris Ferraz de Aragon**, Universidade Federal do Rio de Janeiro/Instituto de Lógica, Filosofia e Teoria da Ciência, BRASIL

Virtual Reality technology offers opportunities to create new products, which could be applied to the cognitive rehabilitation of people with acquired brain injury or neurological/psychiatric disorders. The effects provided by Virtual Environments (VE) stimulate cerebral neuroplastic changes, enhancing the rehabilitation process. This article discusses issues related to this field and presents the main features of an Integrated Virtual Environment for Cognitive Rehabilitation development process. Finally, initial results of an experiment with a group of schizophrenic patients are presented.

Design issues on interactive environments for children with autism, **Kerstin Dautenhahn**, University of Hertfordshire, UK

This article addresses design issues that are relevant in the AURORA project which aims at developing an autonomous, mobile robot as a therapeutic tool for children with autism. Cognitive theories of mind-reading are discussed and related to the AURORA project. This approach is put in the broader context of interactive environments, which autonomous mobile robots are a special case of. Implications of this research for interactive environments in general, and virtual environments in particular are discussed.

Application of virtual reality technology to the assessment and training of powered wheelchair users, **Andrew Harrison, Gary Derwent, Anne Enticknap, David Rose and Elizabeth Attree**, Royal Hospital for Neuro-disability/University of East London, UK

The current study presents quantitative and qualitative data concerning the development and application of two non-immersive virtual environments (VEs) to the assessment and training of adult powered wheelchair users with complex neurological impairments. Aspects of manoeuvrability skills and route-finding were addressed. Results indicated that whilst the participants considered the VEs to be realistic and well represented, and the tasks reflected the skills needed to manoeuvre a powered wheelchair, completing the manoeuvrability tasks was more challenging in the VE than in real-life. Implications of these findings are discussed. Additional data are provided from two patients who commenced a series of training sessions using the manoeuvrability skills VE.

Development of a wheelchair virtual reality platform for use in evaluating wheelchair access, **Colin Harrison, Phillipa Dall, Michael Grant, Malcolm Granat, Thomas Maver** and **Bernard Conway**, University of Strathclyde/Wolfson Centre, Glasgow, UK

In the UK the Disability Discrimination Act 1995 aims to end discrimination against disabled people. Importantly the Act gives the disabled community new employment and access rights. Central to these rights will be an obligation for employers and organisations to provide premises which do not disadvantage disabled people. Many disabled people rely on wheelchairs for mobility. However, many buildings do not provide conditions suited to wheelchair users. This project aims to provide instrumentation allowing wheelchair navigation within virtual buildings. The provision of such instrumentation assists architects in identifying the needs of wheelchair users at the design stage. Central to this project is the need to provide a platform which can accommodate a range of wheelchair types, that will map intended wheelchair motion into a virtual world and that has the capacity to provide feedback to the user reflecting changes in floor surface characteristics and slope. The project represents a collaborative effort between architects, bioengineers and user groups and will be comprised of stages related to platform design, construction, interfacing, testing and user evaluation.

Virtual reality and stroke assessment: therapists perspectives, **David Hilton, Sue Cobb** and **Tony Pridmore**, University of Nottingham, UK

Involving users in the early stages of design has implications for the development, usability, acceptance and implementation of new computer systems. A project exploring the practical application of virtual reality to stroke assessment recently commenced at the University of Nottingham, with an emphasis on user centred design. A consortium of stroke therapists and researchers has guided the direction of the project through their involvement at the early planning stage. The consortium has provided broad guidelines for design, potential applications and identified barriers to this technology being routinely used in stroke assessment.

Basic issues concerning visually impaired people's use of haptic displays, **Gunnar Jansson**, Uppsala University, SWEDEN

Haptic displays present a potential solution to the old problem of rendering pictorial information about 3D aspects of an object or scene to people with vision problems. The aim of the paper is to discuss some basic issues of importance for the usefulness of these displays for visually impaired people: 1) the over-view of a virtual object or scene available for exploration with only one point at a time; 2) the limited spatial resolution of haptics; 3) the potential effects of learning; 4) the necessity of simplifying pictorial information; and 5) the enhancement of tactile information with auditory and visual information.

Internet based manipulator telepresence, **Ton ten Kate, Paola Zizola, Bart Driessen** and **Koos van Woerden**, TNO Institute of Applied Physics, The NETHERLANDS

A wheelchair based manipulator MANUS for severely handicapped people is in use with over one hundred people in their homes. Assessment, telepresence, training and communication among users and between users and professionals are helpful in many phases of acquisition and use of such a manipulator. Services and technologies are developed in the EU supported project Commanus (remote diagnosis, remote optimisation, and remote control). Internet communications with both real and virtual real functions are described in this paper.

Community access through technology project: using virtual reality technologies for community integration, **Jane Kaufman Broida, Clark Germann, Scott Houck** and **Jeffrey Broida**, Metropolitan State College of Denver, USA

The Community Access Through Technology project uses virtual reality and other advanced technologies to produce simulations of community resources. The virtual environment is created using Quick Time Virtual Reality, and access annotations, interactive maps, and digital video are added to enhance the experience of the user. To determine the efficacy of the virtual reality in reducing anxiety, the present study was conducted. Subjects were randomly assigned to one of three groups: control group, virtual reality treatment group, or leisure education-virtual reality treatment group. Results suggest that the virtual tour increased subjects recreation knowledge but had a negative effect on anxiety levels. However, subjects in the leisure education-virtual reality treatment group experienced significant recreation information gain and reduced anxiety. Further research examining more immersive virtual environments and use of additional physiological measures are recommended.

Multi-sensory virtual environment for supporting blind persons' acquisition of spatial cognitive mapping, orientation, and mobility skills, **Orly Lahav** and **David Mioduser**, Tel Aviv University, ISRAEL

Mental mapping of spaces, and of the possible paths for navigating through these spaces, is essential for the development of efficient orientation and mobility skills. The work reported here is based on the assumption that the supply of appropriate spatial information through compensatory channels (conceptual and perceptual), may contribute to the blind people's spatial performance. We developed a multisensory virtual environment simulating real-life spaces. This virtual environment comprises developer / teacher mode and learning mode.

Using haptic feedback to enhance computer interaction for motion-impaired users, **Patrick Langdon, Simeon Keates, John Clarkson**, and **Peter Robinson**, University of Cambridge, UK

For users with motion impairments, the standard keyboard and mouse arrangement for computer access often presents problems. Other approaches have to be adopted to overcome this. There is evidence to suggest that increasing the degrees-of-freedom, and hence bandwidth, of human-computer interaction (HCI), can improve interaction rates if implemented carefully. Haptic feedback is not really exploited in the existing HCI paradigm, so offers a potential method for broadening the interaction bandwidth by complementing the existing interaction structure. This paper describes a series of pilot studies to assess the effectiveness of two possible methods for incorporating haptic feedback into the interaction. The aim was firstly to ascertain whether the motion-impaired could detect the feedback successfully and then to assess whether the feedback may be of benefit. Two experiments were performed, one to test vibrotactile feedback and the other force feedback. The vibrotactile results were inconclusive, but the force feedback results were very positive.

Access to virtual learning environments for people with learning difficulties, **Tanya Lannen, David Brown** and **Heather Powell**, Nottingham Trent University, UK

An evaluation of virtual learning environments, developed to teach independent living skills to people with learning difficulties, found that individuals differed in the amount of support required to use the input devices. This paper describes the employment of a user-centred design methodology to design, develop and evaluate a virtual environment hardware interface for people with learning difficulties. Central to this methodology is 'usability', a crucial factor in the production of a successful human-computer interface. The completion of this study should result in the production of a virtual environment interface for people with learning difficulties, which satisfies ISO 9241 (the British Standard giving guidance on usability).

Special considerations for navigation and interaction in virtual environments for people with brain injury, **Anita Lindén, Roy Davies, Kerstin Boschian, Ulf Minör, Robert Olsson, Bengt Sonesson, Mattias Wallergård** and **Gerd Johansson**, Lund University Hospital/University of Lund, SWEDEN

When a Virtual Environment (VE) is designed, decisions regarding the navigation of the viewpoint, interaction with objects, and the behaviour of the VE itself are made. Each of these can affect the usability and the cognitive load on the user. A VE that had previously been constructed as a prototype tool for the assessment of brain injury has been studied to establish the consequences of such design decisions. Six people, two with brain injury, have used the VE to perform a specific task (brewing coffee) a total of ten times over two sessions separated by a week. These trials were video recorded and analysed. Results and implications are presented and discussed.

The many rooms of the virtual work-place, **Magnus Magnusson**, Karlstads Universitet, SWEDEN

Since the mid-90's the University of Karlstad has been involved in research work on the usage of so called videotelephony in therapeutical work as well as studies in common social distance interaction. Four main projects have been presented during a five-year period:

- Videtelephony and language training for people with Aphasia
- Videtelephony and language training for people with Mental Retardation
- Videotelephony as a network tool for speech pathologists
- Videotelephony as a text telephone for people with language and speech impairment

At the moment the projects have resulted concretely in some 20 videophones installed all over the country and some international tests as well.

A main ingredient in the projects has been to study the social importance of this technology as well as the educational possibilities in the technology, that is, how learning is amplified or not through the usage of videotelephony. The final aim of all the projects is five fold. First we want to establish a well founded description of the quality of the communication situation in relation to its physical counterpart. Secondly we want to study cost-effective alternatives in the professional care of people with speech and language problems. Thirdly we want to make this technology a commonly used tool among speech pathologists and therapists in the whole of Sweden since its multifunctionality seems to offer new professional possibilities. Fourthly, we want to evaluate the methodologies which might evolve. Finally, we want to see in what ways this technology can support and alleviate the social communication patterns of the specialists as well as the service users, in other words, the people with different sorts of communication disabilities. The equipment used are in almost all cases 2×64 kB/s ISDN-based and also desktop video conferencing, that is, systems integrated into personal computers.

Audio space invaders, **Rachel McCrindle** and **David Symons**, University of Reading, UK

Whilst advances are underway in various areas to ease and encourage disabled uptake of new technology, very little emphasis to date has been placed on making the games market accessible to all. The aims of the described work have been twofold. Firstly, to prove that the standard features of a traditional space invader game can be replicated using a 3-D audio (ambisonic) environment. Secondly, through combining audio and visual interfaces with force feedback joystick movement that it is possible to produce a multi-modal game that can be played by both sighted and non-sighted users, thereby enabling them to share the same gaming experience. This paper describes the development and features of the resultant *Audio Space Invaders* game.

Peripheral responses to a mental-stress inducing virtual environment experience, **Michael Meehan, Luigi Pugnetti, Fabio Riva, Elena Barbieri, Laura Mendozzi** and **Eugenia Carmagnani**, University of North Carolina, USA/Don Gnocchi Foundation, European Biofeedback Association and Istituto Clinico S. Ambrogio, ITALY

Virtual environments (VEs) are used increasingly in the education and training of people with disabilities. When utilizing these VEs, it is important to know 1) whether they are effective in the manner desired and 2) whether there are side effects from them. This exploratory study looks at both issues. This paper describes a study in which we observe a predictable pattern of both stress related to the content of the VE and a pattern of relaxation over time (30 minutes – 1 hour) in the VE.

VIRT – factory trainer project. A generic productive process to train persons with disabilities, **Laura Mendozzi, Luigi Pugnetti, Elena Barbieri, Elizabeth Attree, David Rose, Walter Moro, Angelo Loconte, Begoña Corrales, Leocadie Maj, Anthony Elliot-Square, Franco Massara** and **Enzo Cutelli**, Don Gnocchi Foundation, ITALY/University of East London, UK/Cooperativa "Il Melograno", ITALY/Cooperativa CSLS, ITALY/FEPROAMI, SPAIN/UNAPEI, FRANCE/Third Dimension Ltd, UK/CIRAH, ITALY

The production of a desktop VR package to be used by trainers and educators of mentally disabled subjects who seek employment in sheltered factories has been the goal of an EC funded project named VIRT. Three virtual training environments featuring a warehouse, a workshop and an office allow the trainees to practice with typical tasks such as the assembling and the handling of materials and goods. The virtual environments are flexible and can be easily changed to create variants of the basic tasks or to change their level of complexity. The warehouse and the workshop have been extensively tested by 20 disabled workers who had no previous exposure to VR and who worked under close supervision in two Italian sheltered factories during the late period of development. Every trainee spent 96 hours practising on the VIRT-Factory Trainer environments. This activity greatly contributed to the refinement of the product and to the collection of data concerning issues such as learning of procedures and tasks, adaptation to the interaction devices and system responses, and transfer of skills. Learning was apparent even in subjects with rather severe mental insufficiency. Initial difficulties with the interaction devices were greatly diminished after a few weeks of training in all subjects. There is also initial evidence from group analyses that transfer of skills to analogous real tasks may occur. Tutors reported an increase in motivation for work in all participants, which did not change with time. It is concluded that desktop VR training can be proposed to assist the training of mentally disabled workers and that it may produce both specific and unspecific favourable effects. The package is now being distributed to interested institutions and professionals for an additional extended assessment.

Using immersive virtual reality to test allocentric spatial memory impairment following unilateral unilateral temporal lobectomy, **Robin Morris, David Parslow** and **Michael Recce**, Institute of Psychiatry, UK/New Jersey Institute of Technology, USA

Immersive virtual reality was used to investigate spatial memory in 17 right and 19 left unilateral temporal lobectomy patients and 18 control subjects. The subjects were administered a task consisting of a virtual room and table with radially arranged 'shells' on top. The subjects moved around the table and had to find a blue cube, which was under one of the shells. On subsequent searches, the cube moved to a new location and the subject had to find it whilst avoiding the previous location, and so on until all locations had been used. A selective deficit was observed in the right temporal lobectomy group only, linking allocentric memory to the function of the right hippocampal formation.

The effect of interactive virtual environment training on independent safe street crossing of right CVA patients with unilateral spatial neglect, **Yuval Naveh, Noomi Katz** and **Patrice (Tamar) Weiss**, Hadassah-Hebrew University, Jerusalem, ISRAEL

Unilateral spatial neglect is defined as a disorder in which a patient fails to pay attention to stimuli presented to the contralateral side of the lesion; it is known to be associated with decreased functional independence. Our objective was to determine the suitability and feasibility of using a PC-based, non-immersive VR system for training individuals with unilateral spatial neglect to cross streets in a safe and vigilant manner. A virtual environment, consisting of a typical city street, was programmed via Superscape's™ 3D-Webmaster, a 3D web-authoring tool. Twelve subjects, aged 55 to 75 years, participated. Results demonstrated that this virtual environment was suitable in both its cognitive and motor demands for the targeted population. With very few exceptions, the control subjects were able to complete all levels of the program with success. The performance of the patient subjects was considerably more variable, and they were able to complete fewer levels, and usually took more time to do so. The results indicate that the virtual reality training is likely to prove beneficial to people who have difficulty with street crossing.

Designing virtual learning environments for people with learning disabilities: usability issues, **Helen Neale, Sue Cobb** and **John Wilson**, University of Nottingham, UK

The Virtual Reality Applications Research Team (VIRART) has been developing communication and experiential Virtual Learning Environments (VLEs) for people with learning disabilities since 1991. As a human-factors-based research group, we have always been aware of usability issues and the importance of consideration of user needs and abilities in any design development process. However, the infancy of VR for use by the general public and lack of VE applications, particularly for special needs users, has meant that there are few examples of usability studies and a general lack of design guidelines. This paper outlines design considerations in development of virtual learning environments and highlights usability issues identified via observation of users with learning disabilities. Specific usability problems were identified relating to communication, navigation and interaction. Examples are given and recommendations for VE design guidelines are suggested.

Inhabited interfaces: attentive conversational agents that help, **Anton Nijholt, Dirk Heylen** and **Roel Vertegaal**, University of Twente, The NETHERLANDS/Queen's University, Ontario, CANADA

We discuss the role of attentive agents in virtual reality interfaces. This discussion is guided by experiences and experiments with a virtual reality environment we designed and implemented. In this environment we have introduced agents, sometimes embodied, with which the users can communicate using different input modalities. These agents provide information or are able to perform certain transactions or they help the user in finding her way in the virtual environment, allowing a mix of user exploration and guidance. Among the input modalities that are considered are speech, natural language, mouse and keyboard and gaze. Output includes natural language, visual speech, changes in the virtual environment, animations and menus. Gradually this environment evolves to an environment where multiple users and agents live and communicate with each other. Apart from offering different input modalities and attentive agents, in the near future we also hope to be able, based on current experiments, to offer suggestions to the users based on preferences obtained from their user profile and their visit history.

Simulation of the behaviour of a powered wheelchair using virtual reality, **Hafid Niniss** and **Abdellah Nadif**, Université de Metz, FRANCE

This paper describes the firsts results of a project of simulator for powered wheelchair, using Virtual Reality. We have simulated the kinematics of an existing intelligent wheelchair, which was designed in order to facilitate the driving of a powered wheelchair. We also present the integration of modeled ultrasonic sensors in the simulation.

Development of social skills amongst adults with Asperger's Syndrome using virtual environments: the 'AS Interactive' project, **Sarah Parsons, Luke Beardon, Helen Neale, Gail Reynard, Richard Eastgate, John R. Wilson, Sue Cobb, Steve Benford, Peter Mitchell** and **Eileen Hopkins**, University of Nottingham/National Autistic Society, UK

People with High-Functioning Autism, or Asperger's Syndrome (AS), are characterised by significantly impaired social understanding. Virtual environments may provide the ideal method for social skills training because many of the confusing inputs in 'real world' interactions can be removed. This paper outlines the rationale and methodology of the *AS Interactive* project. This multidisciplinary project incorporates a user-centred design and aims to develop and evaluate the use of virtual environments to support and enhance social skills amongst adults with AS. The potential for the use of Collaborative virtual environments for developing social awareness is also discussed.

Cognitive intervention through virtual environments among deaf and hard-of-hearing children, **David Passig** and **Sigal Eden**, Bar-Ilan University, ISRAEL

The deficiencies of the auditory sense in the hearing-impaired raises the question as to the extent to which this deficiency affects their cognitive and intellectual skills. Researchers have found, that in regard with reasoning, particularly when the process of induction is required, hearing-impaired children usually have difficulties. Another cognitive process, which hearing-impaired children have difficulties in, is the ability to think in a flexible way. Studies have proven that hearing-impaired children tend to be more concrete and rigid in their thought processes. They usually choose one familiar means of solving problems and use it to deal with most of the problems that they encounter.

In recent years, one can identify a trend for active intervention in the cognitive capabilities of deaf children in a growing effort to improve their intellectual functioning. The uniqueness of this study is the use it makes of Virtual Reality, as a tool for improving structural inductive processes and the flexible thinking with hearing-impaired children. The results clearly indicate that practicing with VR 3D spatial rotations significantly improved inductive thinking and flexible thinking.

Haptic virtual environments for blind people: further explorations with the Phantom device, **Helen Petrie, Paul Penn, Diana Kornbrot, Stephen Furner** and **Andrew Hardwick**, University of Hertfordshire/British Telecommunications PLC, UK

The development of force feedback devices to add haptic information to virtual environments (VEs) has important implications for both able-bodied and disabled computer users. A study is presented in which blind and sighted participants used a PHANToM 1.0 force feedback device to feel a range of virtual grooved textures using both a thimble and stylus interaction device. Although there was no significant difference between blind and sighted participants, there were individual differences in the way the textures were perceived which have important implications for the use of haptic information in VEs. The stylus was found to produce more sensitive perception of the textures than the thimble, for both blind and participants.

More on central nervous system correlates of virtual reality testing, **Luigi Pugnetti, Michael Meehan, Laura Mendozzi, Fabio Riva, Elena Barbieri,** and **Eugenia Carmagnani**, Don Gnocchi Foundation, Italy/University of North Carolina, USA/European Biofeedback Association and Istituto Clinico S. Ambrogio, ITALY

Polygraphic recordings of EEG and peripheral variables of 10 healthy volunteers taking a VR-based cognitive testing were analysed to describe the phenomenology of short-term and long-term EEG and EP changes and to extract psycophysiological indicators of information processing and adaptation. A non-immersive VR setup was used to allow exposures to VR of up to 60 min. Auditory-task irrelevant probes proved effective in tracking participants’ mental fatigue. Strong negative feedback and motor reactions to them produced well formed event-related potentials including anticipatory components, while other ERPs and alpha EEG changes were noticed to be associated with specific VR events. Finally, sustained EEG changes took place which were correlated with successful or failing cognitive strategies. The neurological equipment produced only negligible additional discomfort to the participants. Psychophysiological investigations should be carried out more intensively by those developing applications for the disables because are potentially very informative and suitable to tune and optimise important aspects of VR-based paradigms.

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Virtual environment applications for the assessment and rehabilitation of attention and visuospatial cognitive processes: an update, **Albert Rizzo, Galen Buckwalter, Todd Bowerly, Andre van Rooyen, Jocelyn McGee, Cheryl van der Zaag, Ulrich Neuman, Marcus Thiebaux, Laehyun Kim** and **Clint Chua**, University of Southern California/Fuller Graduate School of Psychology/UCLA, USA

Virtual Reality (VR) technology offers potential for sophisticated new tools that could be applied in the areas of neuropsychological assessment and cognitive rehabilitation. If empirical studies demonstrate effectiveness, virtual environments (VEs) could be of considerable benefit to persons with cognitive and functional impairments due to traumatic brain injury, neurological disorders, and learning disabilities. Testing and training scenarios that would be difficult, if not impossible, to deliver using conventional neuropsychological methods are now being developed to take advantage of the attributes of VEs. VR technology allows for the precise presentation and control of dynamic multi-sensory 3D stimulus environments, as well as the recording of all behavioral responses. This paper will focus on the progress of a VR research program at the University of Southern California that has developed and investigated the use of a series of VEs designed to target: 1) molecular visuospatial skills using a 3D projection-based ImmersaDesk system; and 2) attention (and soon memory and executive functioning) processes within ecologically valid functional scenarios using a Virtual Research V8 Head Mounted Display (HMD). Results from completed research, rationales and methodology of works in progress, and our plan for future work will be discussed. Our primary vision has been to develop VR systems that target cognitive processes and functional skills that are of relevance to a wide range of patient populations with CNS dysfunction. We have also sought to select cognitive/functional targets that intuitively appear well matched to the specific assets available with the VR equipment that is available for our use.

Virtual reality in vocational training of people with learning disabilities, **David Rose, Barbara Brooks** and **Elizabeth Attree**, University of East London, UK

This paper reports a 3-stage investigation of virtual environments (VEs) in vocational training of people with learning disabilities. Stage 1 results showed that active interaction with a VE can give better learning than passive observation and that some of what is learned in a VE can transfer to the real world. Stage 2, a questionnaire survey, identified catering as the most popular choice for a virtual training package. Stage 3, a preliminary evaluation of that package, showed some positive transfer of training to a real kitchen test and provided clear justification for further development of this type of training.

Embodying cognition: a proposal for visualizing mental representations in virtual environments, **Álvaro Sánchez, José María Barreiro** and **Víctor Maojo**, Universidad Politécnica de Madrid, SPAIN

This paper examines the possibility of visualising the most abstract knowledge in virtual environments: mental representations that are involved in the basic cognitive processes. Metaphorisation is a key tool for creating virtual environments capable of embodying what is in the mind. The aim of these environments is to improve the learning and rehabilitation of users with cognitive disabilities. We propose to design symbolic environments in which concepts are converted into a bodily experience by means of the metaphorical projection from the abstract to the physical domain. Our proposal is illustrated by the description of a case study: the representation of categories in a virtual environment for blind children.

Usability and cognitive impact of the interaction with 3D virtual interactive acoustic environments by blind children, **Jaime Sánchez** and **Mauricio Lumbreras**, University of Chile, CHILE

It is known that blind children represent spatial environments with cognitive difficulty. This can be decreased if they are exposed to interactive experiences with acoustic stimuli delivered through spatialized sound software. A few studies have approached this issue by using interactive applications that integrate virtual reality and cognitive tasks to enhance spatial orientation skills. The aim of this research was to implement a field study to detect and analyze cognitive and usability issues involved in the use of an aural environment and the issues of representing navigable structures with only spatial sound. This experimental study has arisen from a challenging pilot research project to a full fledged field-testing research with eleven children during six months in a Chilean school for blind children. The research was implemented by using a kit of cognitive representation tasks, which includes exposure to the 3D acoustic environment, corporal exercises, and experiences with concrete representation materials such as sand, clay, storyfoam, and Lego bricks. The cognitive kit also included activities to represent the perceived environment, the organization of the space, and problem solving related to the interactions with the software. The usability testing of the environment was an explicit issue in the research by using both qualitative and quantitative methods including interviews, survey methods, logging actual use, still pictures, and video tape recording session analysis. The idea was to motivate and engage blind children to explore and interact with virtual entities in challenge-action software and to construct invisibly cognitive spatial mental representations.

The results of the study revealed that blind children can achieve the construction of mental structures rendered with only 3D sound and that spatial imagery is not purely visual by nature, but can be constructed and transferred through spatialized sound. Our hypothesis was fully confirmed revealing that each blind child passes four clear stages in their interaction with the sound environment and performing cognitive tasks: entry, exploration, adaptation, and appropriation. We also conclude that the child possesses both unique skills and pace referred to mental and spatial development, impacting directly on the quality of the topological features obtained in comparison to the ideal reference spatial structure embedded in the software.

Wearable computer for the blind – aiming at a pedestrian's intelligent transport system, **Hiroshi Sasaki, Toshitaka Tateishi, Tomohiro Kuroda, Yoshitsugu Manabe** and **Kunihiro Chihara**, Nara Institute of Science and Technology (NAIST), JAPAN/University of Oulu, FINLAND

As contemporary transport systems including the developing Intelligent Transport System (ITS) is vehicle centered, pedestrians – especially elders and persons with disabilities – are always threatened. This paper proposes a new pedestrian-centered traffic system concept named "Pedestrian's ITS" (P-ITS) based on ubiquitous and wearable computing techniques. This paper focuses on the wearable computer for the blind, one of the weakest areas in traffic systems. As knowledge of surroundings is most important for the blind to walk safely, the paper presents a method to support "surrounding presumption" on the wearable computer.

*Psychological and pedagogic testing of handicapped children with locomotion disorder using multimedia programs***, Cecilia Sik-Lányi** and **Ágnes Molnár-Lányi**, University Veszprém, HUNGARY

We have developed a multimedia-testing program, which helps the testing of cumulatively handicapped children and is specially designed for the testing of handicapped children with locomotive disorder. It has been prepared for the Commission of Investigation and Rehabilitation of Locomotion Disorders and the Centre of Teaching Handicapped Children. The psychological part of the program is the RAVEN test. The pedagogical part of the program contains several tasks the child will find as a playing possibility. Our program had to been developed in such a form that it could be used also by handicapped children with locomotive disorder.

Interactive interfaces for movement rehabilitation in virtual environments, **Martin Smyth** and **John Wann**, University of Reading, UK

This paper discusses a system for movement rehabilitation that uses low-cost widely available input devices supporting force-feedback, enabling the design of an individualised therapy curriculum. Interactive 3D environments present tasks that can be adapted in terms of complexity and ease of goal attainment. The system is focused upon promoting increase in the range of movement, control of tremor, control of limb velocity and control of smoothness of movement. Our system exploits the use of augmented feedback to enable the patient to identify the strategies and sensory cues that support re-organisation of the impaired motor response. Stress is laid on flexible mapping between the limb movement and the virtual environment action; this provides an extensible system to cope with diverse movement (dis-)abilities and also encompass advances in input device technology.

Effective strategies of tutors teaching adults with learning disabilities to use virtual environments, **Penny Standen, David Brown, Roseanna Blake** and **Tracy Proctor**, University of Nottingham/Nottingham Trent University, UK

Nine adults with learning disabilities spent up to twelve sessions with a non-disabled tutor learning to use desktop virtual environments designed to teach independent living skills. Sessions were recorded on videotape and analysed for frequency of tutor behaviours and goals achieved by learners. Before goals could be achieved, the learner had first to master the interaction devices and then learn to navigate around the environment. Preliminary analysis suggests that goal achievement maintains a constant level while instruction about the input devices and specific information about the environment decrease. Behaviours that maintain attention and motivation increase while positive feedback remains constantly high.

Virtual environments as spatial training aids for children and adults with physical disabilities, **Danaë Stanton, Paul Wilson, Nigel Foreman** and **Hester Duffy,** University of Nottingham/University of Leicester/Middlesex University, UK

This paper outlines experimental work on the use of virtual environments in assessing and improving spatial skills in people with physical disabilities. New evidence is presented which suggests that the degree of spatial impairment experienced by physically disabled children varies dependent on early mobility, and that this impairment may persist into the teenage years. We also review an experiment demonstrating transfer of spatial knowledge from a virtual environment to the real world, and outline a proposed follow up study examining virtual experience versus physical model experience. Finally, other studies in progress are outlined that focus on vertical spatial encoding in virtual environments based on larger real world environments and include older users as the target group.

Finger character learning system with visual feedback, **Yoshito Tabata, Tomohiro Kuroda, Yoshitsugu Manabe** and **Kunihiro Chihara**, Nara Institute of Science and Technology (NAIST), JAPAN

Many researches proposed many types of Computer Aided Education (CAE) systems for Japanese Sign Language (JSL). However, foregoing CAE systems for JSL have the problems that they cannot give the differences between targets and answers, and way to revise. The authors propose an innovative CAE system for JSL, which gives users visual information to revise their mistakes utilizing Computer Graphics (CG) animation. This paper presents finger character learning system with visual feedback as a prototype system of the proposed CAE system for JSL, a method to recognize finger characters and a way to give the visual information to revise.

Research and education activities on disability and disabled people at the Virtual University in Nordic countries, **Antti Teittinen** and **Markku Väätäinen**, University of Jyväskylä, FINLAND

This paper describes the practical implementations and possibilities of virtual university for research and education on disability and disabled people. The development of internet technology supports the practise of this mission. In the late 1990s the Finnish Network for the Research on Disability (*http://www.jyu.fi/~vamtutk/lomake.html*) and the Nordic Network on the Disability Research (*http://www.harec.lu.se/NNDR/index.html*) were founded. The members of these networks are mostly non-medical disability researchers and authorities in Nordic countries. With the help of internet technology these networks together are building the virtual university, where it is possible to study disability issues. For example the internet based network makes possible to give a study counselling on-line easily between Nordic countries (Denmark, Finland, Iceland, Norway and Sweden). In these countries several disability organisations and universities are the members of the virtual university project. The development of virtual university and study programmes are coordinated by the board of Nordic Network on the Disability Research (*http://www.harec.lu.se/NNDR/members.html*). So far practical examples are the annual Nordic conference on disability research since 1997, the first doctoral course in 1999 and the publication called "Scandinavian Journal of Disability Research" (*http://www.harec.lu.se/NNDR/activities.html*) since 1999. Besides these activities all the information and advisory services are available via internet and mailinglist. (*http://www.jyu.fi/~vamtutk/tietopal.html* and *http://www.harec.lu.se/NNDR/mailinglist.html*). A long term goal is to wide this project from Nordic countries to other European countries.

The quest for auditory direct manipulation: the sonified Towers of Hanoi, **Fredrik Winberg** and **Sten Olof Hellström**, City University, UK/Kungl Tekniska Hogskolan, SWEDEN

This paper presents a study of an auditory version of the game Towers of Hanoi. The goal of this study was to investigate the nature of continuos presentation and what this could mean when implementing auditory direct manipulation. We also wanted to find out if it was possible to make an auditory interface that met the requirements of a direct manipulation interface. The results showed that it was indeed possible to implement auditory direct manipulation, but using Towers of Hanoi as the underlying model restricted the possibilities of scaling the auditory space. The results also showed that having a limited set of objects, the nature of continuos presentation was not as important as how to interact with the auditory space.

Alghero – Sardinia's Other Coast

To travellers jaded by the Emerald Coast, the Coral Coast — with its breathtaking vistas and friendly people—is a real gem.

Alfred Rosa

University of Vermont, Burlington, Vermont, USA

http://www.uvm.edu/~arosa/alghero.htm

It took us ten years, but we were finally coming home — home to the land of Garibaldi, of prehistoric, fortress-like structures called *nuraghi* and of emerald green waters. As my wife and daughter and I stood on the deck of the *Petrarca*, the overnight ferry from Civitavecchia, the chilly morning air only lent further excitement to our anticipation. The ship began to enter the long, narrow channel to the port of Olbia on the eastern coast of Sardinia accompanied by a small but reassuring *pilota*, or pilot boat, necessary to keep the ship from crashing on the rocks. As we prepared to anchor, the sun began to rise behind us.

We were "coming home" because we had lived on Sardinia ten years earlier. I had been the first Fulbright scholar assigned to teach in Sardinia and the guest of the first Sardinian to be a Fulbright scholar in America. I taught at the Universidá di Sassari, and we lived in the picture-perfect seaside resort city of Alghero.

If Sardinia stands in sharp contrast to the Italian mainland and Sicily, the city of Alghero on the north-western corner of the island provides an even sharper contrast to Sardinia itself. And yet, Alghero happily wears its unique mantle as a place apart in this undeveloped and primitively beautiful land. A sun-drenched city of 40,000 people on Italy's second largest island, Alghero caters to tourists from all over Europe. The city prides itself on being a more genuine and natural vacation spot than the often-publicised *Costa Smeralda*, summer watering hole on the north-eastern coast and home to movie stars from America and royalty from everywhere else. As the Algherese remind you, theirs is not an artificially created resort, but a city with a long, proud history.

Alghero derives its name from the abundance of seaweed (*alghe*) in the surrounding waters. It was known as *Algarium* in the Middle Ages and *Al Alguer* and *Barcelloneta* under Spanish rule. Surrounded by water on three sides, the "old city" of Alghero, the centre of its traditions and customs, seems once again held captive -not by the Spanish who once dominated the city for some 360 years - but by the very people who love the city so well. The old city sits within thick fortress walls, interrupted only by solemn towers. These *torre* are not the delicate ones of San Gimignano but massive structures, arresting in size and captivating in the way the sea-mirrored sunlight endlessly plays off their rough textures.

The stone streets of the old city, narrow and lined with shops, are dotted with randomly spaced and seemingly unplanned tiny piazzas. You do not often hear a mother's plaintive "Giovanni!" or "Franca!" issuing from an upper-story window as you might in other neighbourhoods. Here life is quiet and the people rather more subdued. The day's laundry is strung out against the backdrop of elegant Spanish-inspired arches that bridge the streets. Rising above the rooftops, and more easily seen from afar than from close by, is the variegated ceramic dome of the church of *San Michele* and the stately, pointed Aragonese tower of the church of *San Francesco*, two of the old city's most familiar landmarks.

Alghero's origins go back to the tenth century, when the Genoese, with the help of Pisans, turned out the Arabs and obtained grants of land from the Judges of Logudoro, one of the groups of judges that administered Sardinia during the Middle Ages. The Genoese *House of Doria* took possession of the city at the beginning of the twelfth century and held onto it until 1353, when the Catalan fleet defeated the ships of Genoa near Porto Conte on the outskirts of Alghero. The Algherese revolted against the commanding officer of the garrison and killed him. The Spanish responded by sending 12,000 men and 100 galleys to suppress the revolt.

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A treaty was arranged, the original inhabitants were forced to abandon their homes, and the town was then settled by Catalan families. Later, when Charles V wished to use the city as a base of operations against Saracen pirates, he visited Alghero and was so warmly received by its people that he proclaimed them *todos caballeros*, a mark of distinction held in regard to this day by the Algherese.

After Alghero came under Austrian rule with the Treaty of Utrecht in 1713, Spain tried once again to take over the city, but was obliged by the Treaty of London to yield Sardinia to the *House of Savoy*. Alghero was not greatly bothered by foreign influences again until it suffered bombings during World War II. Fearing an invasion by the Allied forces, the Sardinians built bunkers in strategic locations around the city that are still standing today, grim reminders of Alghero's more troubled times.

Of all the contrasts that exist between Alghero and Sardinia, perhaps none is so striking as that which exists between the Algherese and the people from elsewhere on the island. If the Sardinians are noted for their quiet strength, independence, fierce loyalty, bravery, deep-hearted friendliness and, at times, *dour mien*, the generous and hospitable Algherese have a well-earned reputation for combining the best traits of the Sardinian character with an unabashed love of the good life. Neither loud nor overbearing, they nonetheless know how to have a good time. They are people who would rather enjoy the sun, the beaches, and the cafe than do anything else. It is not laziness as such, though it could easily be mistaken for it. The Algherese are quite fashionable; they take to the *passeggiata* as if they had invented it, and nowhere else in Italy have I seen a greater percentage of the local population go about this ritual with such great care.

"What further distinguishes the Algherese from the Sardinian and the Italian," according to Dr. Antonio Deligios, an Algherese and a local historian, "is the persistence of the Catalan language, the turning to the sea and not the interior of the island as a way of life, and the very strict prohibition against any violation of the afternoon siesta in the home. There is an almost sacred observance of this custom," says Deligios, "and you can feel it throughout the town."

Turning seaward yields other rewards to residents and travellers alike. For in the area are to be found the beautiful beaches of *Le Bombarde* and *Porto Conte*, as well as the *Porto Conte*, *Punta Negra*, *Dei Pini* and *El Faro* hotels.

Travelling to the north-east, some 24 kilometres from Alghero, you can drive to the top of *Capo Caccia*, an awesome promontory from which you can descend the daring 654 steps of the famous *Escala del Cabirol*, or Goat's Stairway, to the stunning lake deep in the interior of the cavern known as Neptune's Grotto, the mythical abode of nymphs. Accessible also by tour boat from Alghero, Neptune's Grotto is filled with generously lit pastel stalactites and stalagmites that can be viewed from breathtaking walkways carved out of the stone. Old-timers fondly remember when visitors could row across the lake and when thousands of small candles on small plates floated on the water, creating an otherworldly glow of enchantment in the grand chamber.

Called the *Riviera del Corallo*, Alghero is famous for its coral jewellery and carvings. Every year divers risk their lives to extract the coral from the deep coastal waters surrounding Alghero, and sadly, the sea has exacted its toll for the harvest by taking the lives of a good number of these courageous workers.

The coral in its raw form is branch-like and must be worked into the various shapes necessary to make the beads, rings, earrings and carvings so highly prized by natives and tourists. Walking along the back alleys of the city and peering into the dimly lit workshops, one can see the *artigiani* labouring away as, in typical Italian fashion, they create beautiful objects out of the most unlikely materials. The most prized of the coral is the rare *pelle d'angelo*, or angel skin coral, and the best work comes from the strikingly modern factory and showrooms of Signor Marogna and his family in Piazza Civica. Here you can buy the popular ox-blood coral and, while you wait, have 18-karat gold and coral rings fitted to size with a deftness that belies the difficulty of the work. There are literally dozens of such shops throughout the area.

While coral jewellery helps support the modern Algherese, the town's *nuraghi* provide a link with their past. The notable *nuraghe* of *Palmavera,* one of the 7,000 cone-shaped buildings thought to have served as fortresses throughout Sardinia, is located about nine kilometres north of Alghero. The main *nuraghe* is constructed of stone stacked without the aid of mortar and sits in the centre of the site. It is entered through a low doorway, requiring that you stoop as you pass into the barren circular main chamber, which has no windows or other doorways. This *nuraghe*, and the site in general, is interesting because it exhibits two distinct building styles and is thought, therefore, to have been rebuilt around 880 B.C., toward the end of the *nuraghe* civilization (1500–500 B.C.). It is believed that at the time of the reconstruction the lesser *nuraghe*, as well as the smaller, rectangular structures that encircle both buildings, were added to the site. Standing in this spot one is overwhelmed by an eerieness similar to that which envelops the ruins of *Paestum* and *Agrigento*, and yet it is stranger still. Who were these people? What were they really like? Why did they build these mysterious structures? These are questions that naturally come to mind here, questions that to this day remain unanswered.

This is an area where, in many ways, time seems to have stood still. Although no longer used as fortresses, the *nuraghi* play an integral part in the lives of the Algherese, giving shelter to their flocks. The time-honoured work of the herdsmen has not changed over the centuries, and the *pastori* of Alghero and its environs still spend lonely days and nights tending to a good number of Sardinia's 2.5 million sheep (which constitute one-third of Italy's flocks). It is not surprising then that succulent young lamb is commonplace on the family table.

Sardinian food is simple and hearty, but while in Alghero you can benefit from the demanding Sardinian who, when it comes to eating in restaurants, makes even the most fastidious of restaurant-goers appear lackadaisical. In such excellent restaurants as *La Lepanto, Il Pavone*, *Da Bruno*, *Dieci Metri*, *Il Tuguri*, *Palau Real* and *La Muraglia* one can be adventuresome and try some of the more unusual varieties of the freshest seafood from the morning's catch. A restaurateur in Alghero would no sooner dare display a fish whose eyes did not have the necessary sparkle of freshness than he would commit a heinous crime.

As a New Englander and a fancier of Maine lobster, I have come to regard the Sardinian *aragosta* as superior to our own in sweetness and delicacy. I have also enjoyed in Alghero a dish that I have not experienced elsewhere in Italy: *spaghetti alla bottarga*. The dish is made with mullet or tunny eggs, which are shaped into bars, dried, hardened and then grated over the freshly cooked pasta mixed with olive oil. The result is a specialty reminiscent of, but much more interesting than, *spaghetti con acciughe*. Because of its great cost, *bottarga* is treated like gold dust and used very sparingly. The wines from the vineyards that surround Alghero and that so beautifully stretch down to the sea are not well known and are, in my opinion, vastly underrated. In particular, *I Piani*, *Anghelu Ruju* and *Cannonau* are some of the region's more memorable offerings. And those from the house of *Sella* and *Mosca* are some of the finest I have tasted in Italy.

We felt at home in this remarkable place not only because we had lived there before but also because Alghero is *simpatico*, and you needn't feel that being a visitor puts all kinds of obligations on you. The intense sun, the pleasant food, the coral-flecked beaches, the prehistoric sights and, best of all, the Algherese themselves made for a truly memorable homecoming.

Alfred Rosa is Professor of English at the University of Vermont where he teaches courses in linguistics, writing, Italian American literature, and editing and publishing. He was a Fulbright Lecturer at the Universidá di Sassari in 1973-74 and lived in Alghero during that period.

ICDVRAT 2000

Session I. Enhancing Mobility I

Chair: Albert Rizzo

Development of a wheelchair virtual reality platform for use in evaluating wheelchair access

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[1]*http://www.strath.ac.uk/Departments/Architecture/VEL/intro.htm*
[2]*http://www.strath.ac.uk/Departments/BioEng/*

ABSTRACT

In the UK the Disability Discrimination Act 1995 aims to end discrimination against disabled people. Importantly the Act gives the disabled community new employment and access rights. Central to these rights will be an obligation for employers and organisations to provide premises which do not disadvantage disabled people. Many disabled people rely on wheelchairs for mobility. However, many buildings do not provide conditions suited to wheelchair users. This project aims to provide instrumentation allowing wheelchair navigation within virtual buildings. The provision of such instrumentation assists architects in identifying the needs of wheelchair users at the design stage. Central to this project is the need to provide a platform which can accommodate a range of wheelchair types, that will map intended wheelchair motion into a virtual world and that has the capacity to provide feedback to the user reflecting changes in floor surface characteristics and slope. The project represents a collaborative effort between architects, bioengineers and user groups and will be comprised of stages related to platform design, construction, interfacing, testing and user evaluation.

1. INTRODUCTION

With the increasing age profile of developed nations due to the improved health care coupled and reducing mortality rates (Tuljapurkar et al.,2000) there will be a continual increase in the number of people becoming reliant on wheelchairs for mobility as a consequence of disease or injury. In most societies wheelchair users are often discriminated against in areas such as employment and education due in large part to inadequate access provision to the built environment. This can lead to a below average standard of living and the need for a lifetime of state support. The development of a virtual reality facility which allows wheelchair users to explore virtual representations of the built environment should, if appropriately utilised by user groups and architects, lead to socio-economic benefits to a large group of disabled people through improved building design and therefore equal opportunities. In addition, the use of virtual reality systems where navigation is integrated with the sensing of intended motion of wheelchairs (or other forms of assistive devices) will be of benefit to those groups who need to examine compliance with the requirements of equal opportunity legislation. This could lead to the establishment and widespread adoption of design standards relating to building design for wheelchair access.

The long term objectives of this project are to provide a virtual reality facility that can be used to generate, via an interaction between architects, designers and wheel chair users, guidelines which address the issue of wheelchair access to, and within, the built environment. The project aims to design and build a wheelchair motion platform through which wheelchair users can explore virtual representations of buildings. It is envisaged that such a facility would form a powerful and cost effective means of evaluating wheelchair access provision early in the design of new buildings and in the redevelopment of existing buildings (Forest and Gombas 1995). Accordingly the following preliminary objectives need to be met:

- The design and construction of a manual wheelchair motion platform that can accurately monitor intended wheelchair motion and can provide physical and optical feedback to the wheelchair user on the presence of virtual obstacles or changes in floor coverings or slope.
- Interface the platform with a Silicon Graphics virtual reality facility to provide an immersive virtual environment within which navigation is linked to the intended wheelchair motion.
- Generate virtual representations of a range of building types in order to test and calibrate the performance of the platform and perform an evaluation of the system by wheelchair users.

2. WHEELCHAIR DRIVEN VR SYSTEM

The facility is comprised of seven functionally separate elements: projection system; image generator; graphics software; motion simulator; roller system; control system; user. An overview of the system is shown in Figure 1.

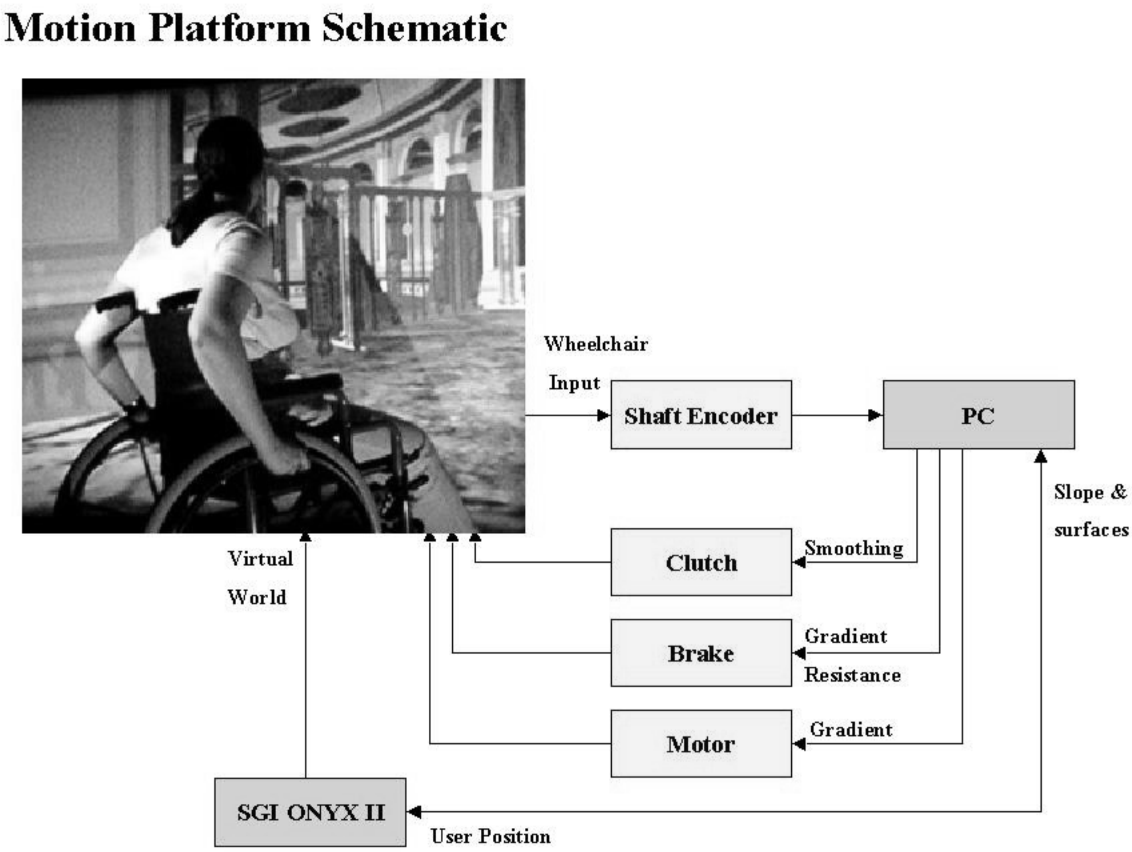

Figure 1. *Layout of the wheelchair motion Platform and Virtual Environment Laboratory (VEL)2.1 Projection system*

2.1 Projection system

The virtual environment is visualised using a three-projector system that provides a 150° by 40°, high-resolution image on a five metre diameter cylindrical screen. Each of the three image channels is edge-blended to provide a seamless display. When viewed from the design eye point the image fills most of the users field of vision providing a highly convincing sense of immersion within the scene.

2.2 Image Generator

Graphics are generated on a twelve-processor Silicon Graphics ONXY II with two graphics pipes. This is capable of processing detailed architectural models at high frame rates in order to provide the desired degree of realism. At each time-step in the simulation the graphics are rendered to three separate output channels, each channel sharing the same eye point but with a different angular offset in azimuth, corresponding to the offsets in the projection system. This circumvents the geometrical distortion inherent in large field of view displays.

2.3 Graphics Software

The software used to drive the virtual environment is based on the Silicon Graphics Performer API. This is a high performance 3-D rendering toolkit for multiprocessed interactive applications. The graphics component is closely coupled to a separate asynchronous module that interfaces between the incoming data from the motion platform control system and the rendering software.

2.4 Motion Simulator

As outlined above, the motion simulator and the graphics software are a close-coupled system. The motion simulator communicates with the control system over a TCP/IP network, and the link between simulator and graphics is via a shared memory segment. The task of the motion simulator is to accept incoming data from the control system. This data relates to the individual incremental angular displacement of both wheels on the motion platform. This data is compared to the previous increment, to determine whether the wheel is rotated forward or backward, and to pass this information to the next stage of the algorithm. The basis of the motion control algorithm is the determination, through an analysis of similar triangles, of the location of the centre of rotation along the rear axle of the virtual wheelchair and the angle through which is turned. From this the transformation of the eye point and rotation of the view vector can be determined.

The graphics application requires the Cartesian co-ordinates of the eye point, plus the yaw, pitch and roll angles of the direction of view. Given the yaw angle the remaining two parameters can be calculated based on the wheelchairs attitude on the floor plane. In the database traversal three rays corresponding to the contact patch of each of the rear wheels and the midpoint of the front axle, are intersected with the floor. The normal vector of the ground plane at these points can then be used to calculate the roll and pitch of the chair and the corresponding view. The same intersection procedure can also be used to identify the surface under each wheel, this information can then be used to index material properties, such as rolling resistance, which can be passed back to the control system.

2.5 Roller System

The roller system is housed within a framework that supports the wheelchair and occupant, and converts wheel motion into an instrumented rotation of the main shaft. The system is duplicated for each wheel of the wheelchair. Mounted on each shaft are the brake, clutch, encoder, inertial mass and the take off for the motor drive. A detailed discussion of the design rationale and function is given in section 3.

2.6 Control System

The control system is based on a standard PC with purpose written software, that interfaces with the image generator via a network link using TCP/IP and with the instrumentation via a General Purpose Interface Board (GPIB). The control system feeds the motion engine of the image generator with incremental readings from the rotary encoders on the motion platform whilst controlling the feedback stimuli to the wheelchair on the basis of data received from the simulation in order to effect changes in floor conditions or collisions.

2.7 Wheelchair User

Each of the above elements forms a linked system that is controlled by the bidirectional flow of information from the wheelchair to the virtual environment, and from the virtual environment to the wheelchair. The feedback loop is by the users visual perception of progress through the virtual environment and by the perceived proprioceptive changes associated with alterations in the rolling resistance of the wheelchair. By closing the feedback loop with a human rather than a further pair of sensor connections, it is expected that any minimal latency or hysteresis in the rest of the communications path will be compensated for by the user.

3. DESIGN OF MOTION PLATFORM

3.1 Manual Wheelchair Interface

The design of the interface between the manual wheelchair and the virtual environment has been specified so that the wheelchair remains fixed in place, with movable driving wheels. In this way the user is not limited within the virtual environment by the constraints of the physical environment. This interface was required to fulfil two main functions. Firstly, it had to be able to transfer the rotation of the driving wheels to provide realistic navigation around the virtual world (Hofstad and Patterson 1994 for modelling characteristics). Secondly, it was to provide additional non-visual (proprioceptive) feedback to the user of the environment represented by the virtual world, in order to match optic flow and visual perception with voluntary motor effort, and thereby enhance the users' experience of navigating the virtual world. Finally, in order that a user could retain their own wheelchair whilst navigating in the virtual environment, the interface has been designed to accommodate a wide range of manual wheelchairs. Figure 2 shows the detailed layout of the principle components of the wheelchair interface.

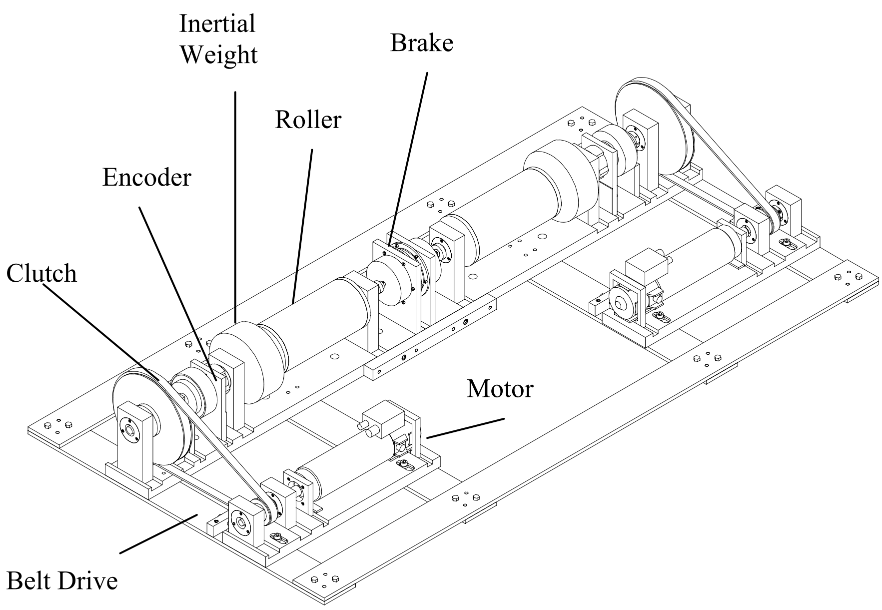

Figure 2. *Physical Components of the Wheelchair Interface without the Cover*

The physical structure of the wheelchair interface is based around a pair of rollers mounted so that one roller is in tangential contact with each of the driving wheels. Frictional contact between the tyre and the roller is sufficient to ensure that the roller rotates simultaneously with each wheel and so could then be used to navigate within the virtual environment. The use of two rollers was required so that differential motion of the driving wheels of the wheelchair could be distinguished to detect turning.

A large number of environmental features were identified for which accessory physical feedback could enhance the visual feedback of the virtual environment. These included slopes and cambers, kerbs, uneven surfaces and different ground surfaces. For the initial design of the wheelchair interface it was decided to concentrate on providing feedback for different ground surfaces and different grades of slope, as these are the features most commonly encountered by the wheelchair user. Different floor surfaces are simulated by altering the resistance to motion of the rollers, when pushing the wheels. A variable torque hysteresis brake is used to provide resistance to motion at each roller. The brake is used to provide increased resistance and so simulate the effect of gravity on the wheelchair when moving up a slope. Simulation of the wheelchair moving down a slope requires active input into the system, providing a torque against which the user can control their movement down the gradient. A variable torque motor is used to provide this input for different grades of slope. Switching between use of motor and brake is accomplished by monitoring the position of the rollers.

An early design proposal suggested that the wheelchair platform should tilt in response to changes in gradient within the computer model. This may have been advantageous because users often vary their seating position to alter their centre of gravity when traversing slopes. However due to the increased complexity of such an implementation, and the level of visual feedback already available, this feature was discounted.

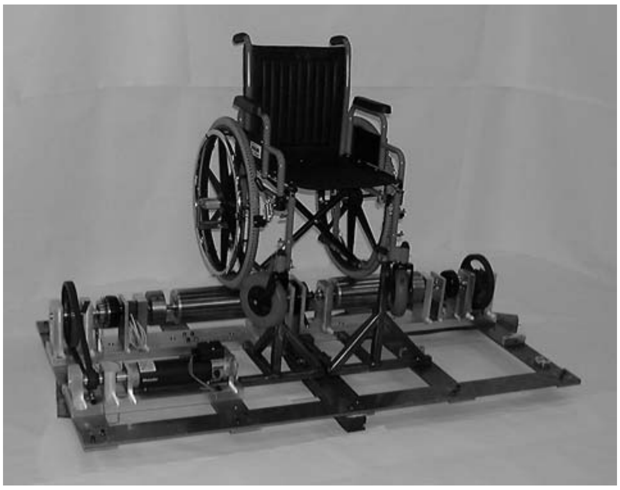

Figure 3. *Photograph of Wheelchair Motion Platform*

3.2 Physical Structure of the Wheelchair Interface

The physical structure of the wheelchair platform is based around a pair of rollers. These are mounted on separate shafts so that one roller is under each driving wheel of the wheelchair. The rollers are 300 mm long so that a range of wheelchair widths can be supported. Each roller is constructed from seamless steel and aluminium discs were inserted into the ends of each tube to close the roller, and to provide a bush to which the axle could be secured.

The roller shaft is supported by a pair of single row radial ball bearings mounted in support pillars, fixed to a solid base plate, as illustrated in figure 3. The roller and space for an inertial mass is between the two bearings. The maximum size of the mass that could be accommodated was a cylinder 65mm long with a diameter of 240mm. Outside the lateral ball bearing, the shaft was machined to accommodate a hollow shaft encoder. The body of the encoder is held with respect to the base plate, while the hollow shaft has been clamped to the roller shaft. Each brake is rigidly mounted coaxial to the roller shaft. The motor is geared to the roller shaft using a toothed belt and is coupled by an electromagnetic clutch.

The entire structure is enclosed by a wooden cover so that the user is protected from the moving parts. Two rectangular holes in the cover allow the rollers to stand slightly proud of the surrounding surface allowing wheel contact. Adjustable straps and bars ensure that the wheelchair is held in place on the rollers, and a ramp allows the user to gain access to the facility. The system is electrically isolated.

3.3 Design Issues for the Wheelchair Interface

Normal translation in a manual wheelchair is a discontinuous motion. Between propulsive pushes the user needs to reposition the arms and during this period the wheelchair decelerates at a rate dependant on environmental and wheelchair characteristics. To simulate realistic navigation in the virtual world using encoder data from the rollers as the control input, requires that roller motion simulates real wheelchair motion with respect to kinematic parameters. These kinematic parameters are dependant on the interaction of the inertia and resistance to motion of the roller system. In the real environment, wheelchair motion consists of rotary motion of the four wheels, and linear motion of the wheelchair and user. When navigating in the virtual environment, the only physical motion is provided by the rotary motion of the rear wheels, the rollers, inertial masses, the brakes and, when engaged, the motors. To provide basic navigation through the virtual environment, a high inertia coupled with a low rolling resistance is needed in the physical interface.

The inertia of the roller system is predominantly determined by the fixed inertia of the contributing components. Provision has been made for the inclusion of an inertial mass for each roller. This allows the inertia of the system to be increased, should the basic inertia of the roller system prove too low, and provides a measure of adjustment to the system.

The biggest design issue has been the reduction of resistance of motion of the system to an acceptable level. The acceptable level was defined as that required for the system to decelerate with similar characteristics to the wheelchair and user when on a smooth level surface such as linoleum. A belt connection considerably increased the overall resistance to motion of the system and was avoided where possible, and therefore the brake was mounted directly coaxial to the roller shaft. The motor needed to be geared with respect to the roller and thus a belt connection was unavoidable. However counteracts the increase in system resistance by increasing the torque provided. An early prototype used needle bearings to mount the roller shaft. The characteristics of the needle bearings resulted in a failure of the roller to be able to match the required deceleration rates, and ball bearings were used in subsequent designs.

Additionally, a single roller per wheel was used rather than two. While a pair of parallel rollers per wheel would offer simple control over wheel positioning, a single roller system gives less rolling resistance. Therefore the platform has had to incorporate a set of adjustable bars and straps which fix the wheelchair in the correct position over the roller systems.

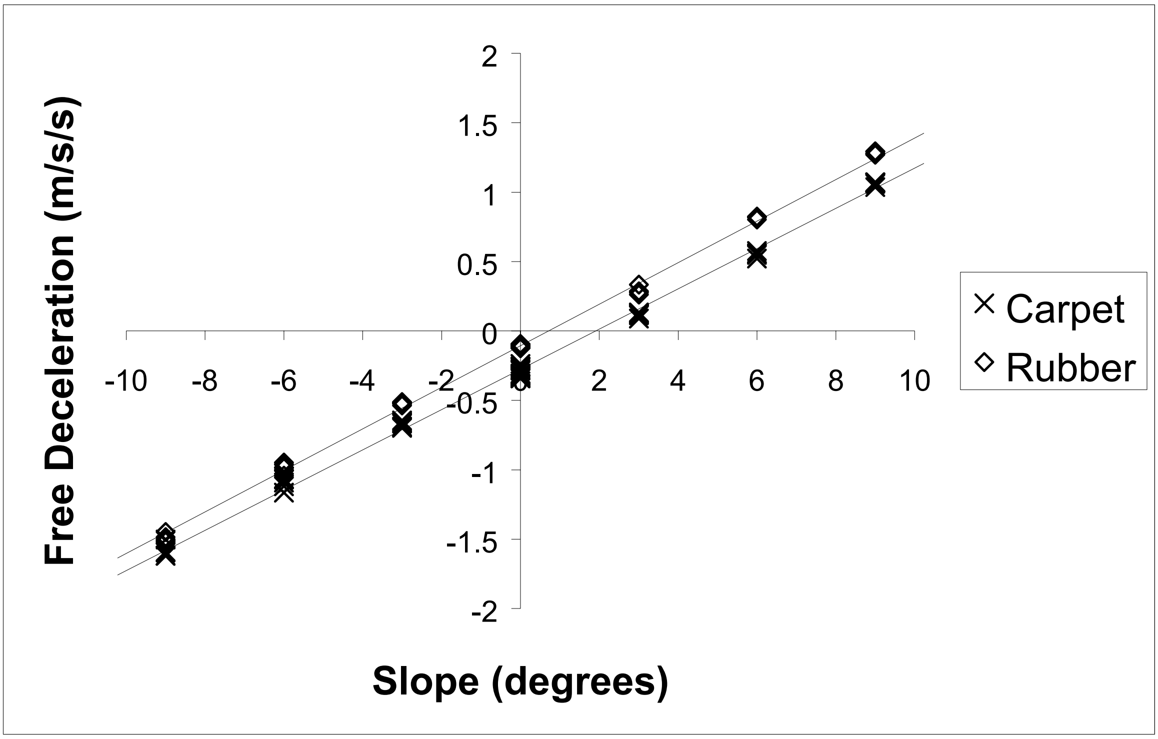

Figure 4 *Measured Free Acceleration for Carpet and Ribbed Rubber on Various Grades of Slope*

3.4 Matching the real world to the Virtual Environment

Defining the kinematics of wheelchair motion with respect to user input, surface and slope conditions, and different wheelchairs can be an involved task with many variables (Kauzlarich and Thacker 1985; Frank and Abel 1989; Hofstad and Patterson 1994). The creation of algorithms to encompass such variability was outwith the scope of this project, and an empirical approach was adopted towards the determination of control settings for various surface considerations. This involved the measurement of the motion of a single wheelchair when there was no user input, for real motion over various surface conditions and when on the wheelchair interface. The condition of no user involvement was used so that it could be reliably reproduced in all experimental circumstances. A rotary encoder was attached to the axle and spokes of one wheel of a basic wheelchair to investigate this relationship. The wheelchair was rolled with no external input over a range of surface coverings, for example ribbed rubber and carpet, and several different grades of slope. The acceleration of the period when there was no external input was calculated. Data has been collected for slope and surface combinations and a best-fit line for free acceleration against slope for each surface was calculated (figure 4). The graph shows a linear relationship between the free deceleration of the wheelchair and the grade of slope. This basic relationship is subject to an offset due to negative acceleration equal to the free deceleration of the wheelchair over each floor surface. A database of the free deceleration of a wheelchair in the real environment has been obtained from which the required free deceleration of the roller system for any particular surface and slope combination can be extrapolated. By knowing the free deceleration of the wheelchair and the roller system, the virtual environment can then be simulated by a range of voltage inputs for the brake and motor.

The kinematics of deceleration also vary depending on wheelchair characteristics, and these must be taken into account when setting up a session with the wheelchair interface. A calibration procedure is required when a user is introduced to the interface for the first time. The diameter of the wheel also need to be input into the control so that the ratio between roller and wheel for different wheelchairs is respected.

4. INTEGRATING MOTION PLATFORM WITH VIRTUAL ENVIRONMENT LABORATORY

4.1 Integrating Mechanical motion Platform and Virtual Environment Laboratory

It was decided at a relatively early stage to use a personal computer as the host for the motion platform and electromechanical devices, as this is a computer that is relatively straightforward to implement using commercially available software and peripherals. The PC could also provide a multi-role capability.

The team had earlier experience using sockets in a Unix to PC environment and this was one of the reasons for using this proven route again. For this reason a PC based solution was chosen, although many other integration routes are possible (Stredney et al 1995), the modular approach means that in the future interfacing to other VEL computers should be straightforward.

4.2 Host Personal Computer

Based on a networked Dell 220 Precision, the PC has a Digital to Analogue (D/A) card driving the clutches, brakes and motors through a purpose built power supply unit, and a commercial motor interface unit. The optical encoders provide feedback to the PC on the position of the rollers in space, and hence the position and orientation of the wheelchair, which is then be sent to the Silicon Graphics machine for conversion into 3D world co-ordinates. Standard geometrical treatments are available which describe the wheelchair dynamics (Stredney et al 1995).

4.3 Communications

The system uses sockets which provide either UDP (User Datagram Protocol) or TCP (Transmission Control Protocol) in order to establish communication between the PC and the VR Platform, currently a Silicon Graphics machine.

The use of this standard technology means that if the VR host is upgraded, the wheelchair motion platform will still be able to be commissioned with little or no difficulty.

5. CONCLUSIONS

The mechanical construction of the wheelchair motion platform is complete, although a certain amount of user calibration is required. The design and manufacture of the platform has proved to be a more complicated task than first estimated due to the requirement to provide low rolling resistance and minimal deflection when loaded by the user. This has meant working to high levels of machining accuracy, and assembly alignment for the eight separate bearings. Since in this application the user must be able to steer, the roller assembly is duplicated for each side resulting in a high quality assembly platform which can accommodate a wide range of wheelchairs, and which has good mechanical performance.

The design has enabled the independent use of brake, clutch, and motors which means that a wide variety of surface and slope conditions can be simulated in as natural a way as possible. These include uphill and downhill slopes combined with smooth and rough surfaces. The design can be evaluated by the user community, which includes architects, building design engineers and healthcare professionals as well as wheelchair users. Uniquely this system gives a sense of feeling of what a proposed design will be like to use in practice, which cannot be duplicated by any other method. Whilst it is possible to evaluate designs using conventional methods, none conveys the actual physical experience of wheelchair use in proposed buildings, which provides solid education and feedback outcomes for the user community.

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Simulation of the behaviour of a powered wheelchair using virtual reality

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ABSTRACT

This paper describes the firsts results of a project of simulator for powered wheelchair, using Virtual Reality. We have simulated the kinematics of an existing intelligent wheelchair, which was designed in order to facilitate the driving of a powered wheelchair. We also present the integration of modeled ultrasonic sensors in the simulation.

1. INTRODUCTION

Recently Virtual Reality has been essential in the field of simulation. This technique indeed allows to build a world which can resemble closely to the real world by leaving the user the possibility of handling the elements. For this reason, the application's fields of RV was spread quickly in the following areas: car and aerospace's industries, architecture, medicine (Çakmak and Kühnapfel 1999), and more recently in the arts like sculpture. Concerning the domain of the handicap, several projects were developed, aiming to build simulators for powered wheelchairs.

These projects pursue various goals:

- design of powered wheelchairs (Inoue and Hirose, 1998),
- drive training for handicapped children (Desbonnet, 1997),
- study the accessibility of public infrastructures to the wheelchairs (Browning, 1993),
- simulate the wheelchair's navigation in domestic environments (Simon, 1997).

The search in progress presented in this article aims to assist disabled people. It is the extension of the VAHM project (Vehicule Autonome pour Handicapés Moteurs) (Bourhis, 1998): it is related to an intelligent system which assists the driver to control the powered wheelchair (Figure 1).

The characteristic feature of this robot is to help controlling the wheelchair by adapting the allocation of the tasks between the handicapped person and the machine as well as possible, accordingly to the degree of the user's disability and the complexity of the environment. During the test phases, it is necessary to involve disabled people. However, this can generate some problems. For each test the user is surrounded by a medical staff, which causes a problem of availability. Moreover, the driving of the wheelchair is not free of collisions with the environment, which could be relatively violent. Therefore, the real tests are affected by material problems; those often induce a waste of time (breakdowns, detection and replacement of a defective component...). Finally, the creation of real environments used for the tests requires generally much time. The use of VR makes possible to carry out the tests in a fictitious world, and thus proposes a solution to these problems.

2. DESCRIPTION OF THE PROJECT OF SIMULATION

The simulation system in progress follows several aims: First of all the platform structure has to simulate as much as possible the powered wheelchair moving in not plane environments (access ramps, roughness of the ground...) Moreover the user will be able to feel accelerations in the same way as in the real world, which will contribute to improve realism of the simulation. This project also aims to develop a support for driving a powered wheelchair. This permits the evaluation of the user's ability to drive, and thus to choose the wheelchair more appropriately. Finally a software tool for a design assistance will come to supplement this system of simulation.

2.1 Presentation of the VAHM2

One of the major projects of the LASC is the design of an intelligent system of assistance to control a powered wheelchair for disabled people. The second prototype in the VAHM project is presented in Figure 1.

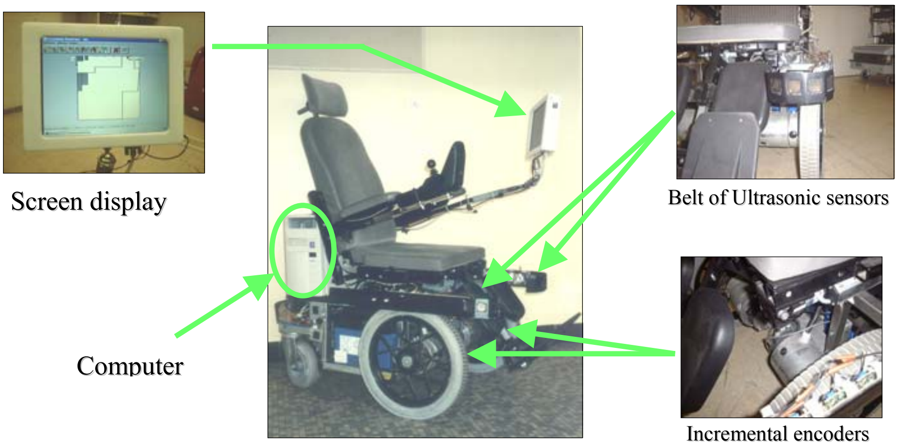

Figure 1. *The VAHM2 prototype.*

The robot is composed of a traditional powered wheelchair equipped with:

- an odometer which estimates the instantaneous position and orientation of the robot knowing the initial position and measuring the rotation of the wheels
- a belt of 16 Ultrasonic Sensors to measure the distances between the wheelchair and the closest obstacles
- a computer that controls the engines and generates high-level tasks as avoiding obstacles or global path planning.
- a display to visualise the graphic interface which manages the interactivity between the man and the machine.

The robot can work under three navigation modes:

- Mode I (manual mode): the robot is used as a traditional wheelchair because its equipment are not activated.
- Mode II (half automatic mode): the navigation is similar to the manual mode, but there is an assistance for operations that could be difficult according to the seriousness of the user's deficiencies. A good example is passing through a door or follow-up a wall...
- Mode III (full automatic mode): it allows the wheelchair to follow a trajectory by itself, connecting two points of the environment which are chosen by the user, avoiding unexpected obstacles. It is the case for example of a chair which has been moved, or a person who crosses the robot trajectory. In these three modes, the user always has the possibility to stop the robot using an emergency button.

2.2 Principle of the present simulator

The current simulator contains a workstation which is equipped with virtual reality helmet. It has to manage the simulation in the virtual world and the interactions between the real worlds and virtual environment.

The user can navigate in a virtual world he had chosen, using the wheelchair accordingly to its three operating modes (Figure 2). The closest aim is to get free of the helmet by projecting the simulation on a giant screen. At the moment the simulation is realised by data exchanged between the real robot and the simulator (Figure 3).

For the simulation of the robot's motion, we have disconnected its wheels from the engines (putting them on neutral position). While the robot is motionless in the real world, it is controlled in the virtual scene by a real joystick (in the case of the manual and assisted modes), or by the path planning unit (in the automatic mode). The odometer of the real robot can estimate the wheelchair's position and orientation using the data of the incremental coders which are placed on the engines' shaft. These data allows the simulator to manage displacements of the robot in the virtual environment. In order to make the robot capable to avoid obstacles which were not initially modeled (for example a moving obstacle), the simulator sends back to the robot the measurements of distance taken by the sensors modeled in the virtual environment. The following step is to place the robot on a plane surface, located at a few centimetres of the ground. Using cylinders on which are placed incremental coders, we can avoid the use of the robot's odometer, and then we can simulate the motion of any ordinary wheelchair. The final step is to equip the platform with jacks, in order to be able to simulate a navigation on inclined surfaces and also simulate the accelerations the pilot is submitted to. The figure 4 shows a design of the final platform.

Figure 2. *Principle of the current simulator.*

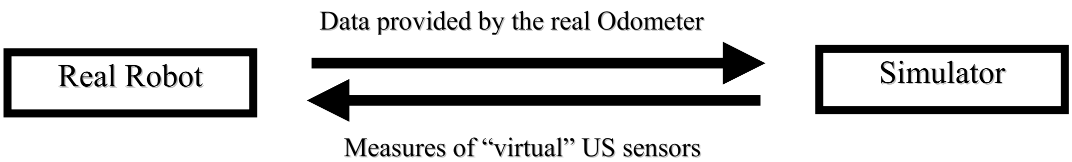

Figure 3. *Data exchange between the real robot end the simulator.*

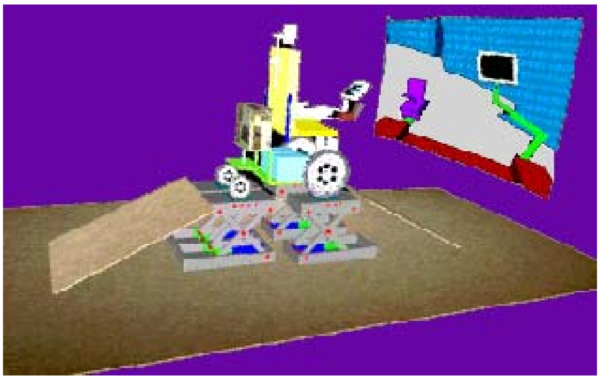

Figure 4. *Design of the simulation platform.*

2.2 Models

2.2.1 US Sensors. In order to be able to navigate safely, the wheelchair needs to measure its distances to the closest obstacles. Since the real wheelchair remains motionless, it is necessary to integrate the simulation with a model of ultrasonic sensors. These " virtual " transducers have to send to the real robot the distances measured during the simulation, like the real sensors do. In a first approach to the problem, we modeled the transducers in an ideal way.

Figure 5 shows an example for the measurement of distance in the simulated environment. Each transducer emits a beam which is totally reflected in the same direction given by the acoustic axis (we have shown only the impact of 2 up to 16 sensors). Currently we use a 2D model (Figure 6) which is an extension of the previous model. We consider the beam angle of the transducer crossed by a discrete number of rays in a horizontal plane. Each ray gives us a measure, and we consider only the smallest returned value. The advantage of this method is its low computation time. Its disadvantage is that the modeled transducer perceives only obstacles located in a plan parallel to the ground. For example, in the case of a table, the transducer will perceive only the table's feet; then a collision may occur between the table's surface and the wheelchair. Using the same concept of a 2D sensor, a study is in progress and it involves an experimental model proposed by Harris (1998). This model is related to the Polaroid 6500 series ultrasonic ranging system (Polaroid, 1991) which we use for the VAHM2. This study should enable us to determine if a 2D model is appropriate for our application, or if it is necessary to extend the model to the 3D case (Figure 6).

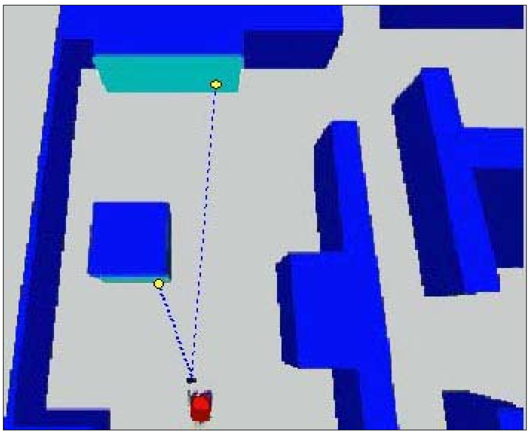

Figure 5. *Example of the measure of the modeled sensor. The measure is done on the acoustic axis of the sensor. We show only 2 up to 16 sensors.*

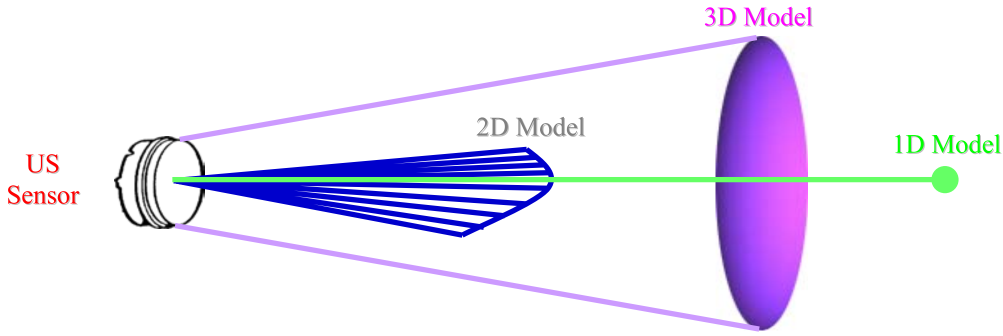

Figure 6. *Models used to simulate the ultrasonic transducer. In the first simulations we used the 1D model, and now we use a 2D mod l based on the previous one: the measure is taken inside a cone, but at a fixed height.*

2.2.2 Kinematic of the VAHM2. Till nowadays we considered in our simulation the wheelchair as a "*free flying point"* (without mass): the control of the wheelchair was done by imposing a trajectory to this point which was taken between the wheels (Niniss, Nadif and Bourhis, 2000).

Using this simple model (Figure 7), we have simulated the wheelchair working under its three navigation modes, but we didn't take into account the kinematics of the wheelchair. The kinematics of the wheelchair was integrated to the simulation in order to study the effects of the different configurations of the wheelchair on the navigation in environments with obstacles (Figure 7).

Placing the driving wheels on the front, on the center or on the back of the wheelchair will influence the way of executing the same task (avoiding an obstacle, half-turn...). For these reasons, it was necessary to consider the instantaneous rotation angle and the speed of each driving wheel to determine the instantaneous position and speed of the wheelchair. In this way the simulated wheelchair can behave more realistically. Like the real wheelchair, the control of the simulated one is based on the tension (controlled by the joystick or the computer) which has to be applied to each engine. The position and the orientation of the wheelchair are estimated by the odometry principle, which considers the measure of rotations of the driving wheels.

Figure 7. *Simulation of the VAHM2 prototype.*

Figure 8 shows how the wheelchair is controlled in the manual mode, for both the real case and the simulated one. When the joystick is pushed forwards or backwards, the two driving wheels turn at the same angular speed and in the same direction ($\omega_l = \omega_r$), which causes a translatory movement. If it is pushed on the right or on the left, the wheels of the wheelchair turn at the same speed, but in opposite direction ($\omega_l = -\omega_r$), which causes a rotation around an axis located in the middle of the wheels. If the joystick is in diagonal position, one of the wheels turns while the other remains motionless, then the wheelchair describes a circle centred on the motionless wheel.

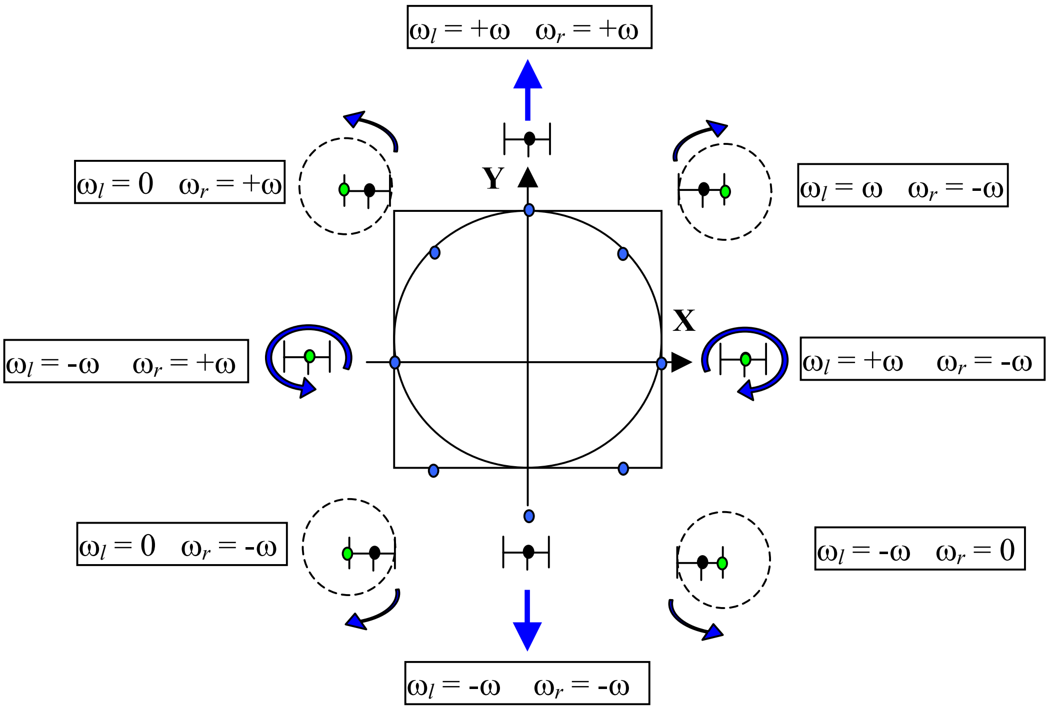

Figure 8. *Control of the wheelchair in the manual mode. ω_l represents the angular speed of the left driving wheel and ω_r is the angular speed of the right driving wheel. We constantly have $0<\omega<\omega_{Max}$, where ω_{max} is the maximal angular speed that can be obtained.*

The kinematics of the simulated wheelchair is a satisfactory approximation of the real wheelchair when the engines reach their stationary state. However for the transient states (for example when we turn the wheelchair on), a dynamic model must be elaborated, to take into account the mass of the physical system composed by wheelchair and the user in order to simulate its inertial aspects.

During the simulation we can use a virtual joystick as well to control the wheelchair. For the moment we can only simulate the VAHM2 prototype, but our final goal is to be able to simulate any kind of powered wheelchair (which will have to be chosen in a data base) using a traditional one. In this prospect, it could be

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interesting to control the “virtual” wheelchair with a simulated joystick. The user has the possibility to control the “virtual” wheelchair inside the simulation using the “virtual” joystick.

The last step is to integrate the computer screen in the simulation. This will allow the user, immersed in the virtual scene, to have access to the graphical interface, (used by the VAHM2) which role is to make a link between the user and the machine.

3. CONCLUSION

We have presented our first simulations of a powered wheelchair using Virtual Reality. To carry out these simulations it was necessary to model a certain number of real elements. The main element is an intelligent system designed in the aim to help driving powered wheelchair. This system can works in three modes (manual mode, semi-automatic mode and full automatic mode). In a previous work we have simulated the three modes of the robot (Niniss et al., 2000), using a simple geometric model for the wheelchair, and also a trivial model for ultrasonic sensors. In this present work, we have taken into account the kinematics of the wheelchair in the simulation. We have studied the wheelchair’s navigation in its manual mode (the other modes are the extensions of this mode), in order to make the behaviour of the simulated wheelchair more realistic. We also used an ideal 2D model for the ultrasonic sensors. A study in progress based on experimental data should permit to evaluate this model and to determine if it is necessary to extend the model of ultrasonic sensors to the 3D case. Finally, for the modeling of environments, we would like to consider the characteristics of the surfaces (roughness, type of material) which determine the way the beam is reflected and then also the measure of distances.

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Application of virtual reality technology to the assessment and training of powered wheelchair users

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ABSTRACT

The current study presents quantitative and qualitative data concerning the development and application of two non-immersive virtual environments (VEs) to the assessment and training of adult powered wheelchair users with complex neurological impairments. Aspects of manoeuvrability skills and route-finding were addressed. Results indicated that whilst the participants considered the VEs to be realistic and well represented, and the tasks reflected the skills needed to manoeuvre a powered wheelchair, completing the manoeuvrability tasks was more challenging in the VE than in real-life. Implications of these findings are discussed. Additional data are provided from two patients who commenced a series of training sessions using the manoeuvrability skills VE.

1. INTRODUCTION

Several authors have examined both the positive and negative implications of powered mobility on peoples' lives. Most reported feeling empowered, being more productive, enjoying more leisure and achieving more self-care (Miles-Tapping, 1997). However, Field (1999) notes that the same technology has also lead to concerns about safety, particularly accidents and injuries involving powered wheelchairs. Due to the high cost of powered wheelchairs, an evaluation usually takes place of the physical and cognitive-perceptual abilities necessary for use of such a chair before one is purchased for an individual. Individual factors include level of intellectual functioning, physical limitations, visual problems and seizure risk (Breed and Ibler, 1982). Despite the increased opportunities that come with powered chairs, Swan et al (1994) suggest that often "the evaluation of user proficiency and the suitability of a given wheelchair is largely guesswork". A detailed assessment of an individual's seating needs is required before provision of an optimal seating system. Subsequently, training is required in order to improve the users independent mobility. Evaluation tools have been developed for clinical use (Field, 1999). However, training in a powered wheelchair can be expensive in terms of staff input and can be potentially unsafe (Hasdai et al, 1998). Training is often carried out using a wheelchair loaned to the patient which may not fully meet their needs (Swan et al, 1994). Children learning to use powered chairs are often frustrated initially as they have not yet developed adequate control over the chair, leading to collisions (Desbonnet et al., 1998).

Hasdai et al (1998) suggest that a joystick controlled computer simulation may be a useful solution for training physically disabled children with skills analogous to those needed to use powered wheelchairs. A simulated training environment may prove motivating and would reduce the danger of collisions during the training phase as the patient would not actually be moving. Several studies have addressed the efficacy of computer simulations as a means of training powered wheelchair users. Hasdai et al. (1998) compared physically disabled children with and without prior experience of driving a powered chair. Both groups were assessed using a functional test devised for the research and a computer simulation consisting of navigation through two-dimensional mazes similar in layout to a school environment. The inexperienced group then received training for 30-45 minutes twice a week for up to 12 weeks before being assessed again. Training consisted of exposure to increasingly difficult mazes with verbal instructions and feedback. On functional evaluation, the inexperienced group showed significant improvement in performance after training but did not reach the standard of the experienced drivers. Prior to training, the simulator scores (based on number of collisions and time taken to complete the maze) of the inexperienced group were significantly lower than those of the experienced group. However, following simulator training, the group's standard rose to that of the experienced drivers. The authors concede that the two-dimensional simulator was unsophisticated in comparison to technologies allowing virtual reality based simulators. However, they conclude that the wheelchair simulator developed would be useful "in the absence of an opportunity to engage in, and as preparation for, actual driving experience".

Inman, Loge and Leavens (1997) used three virtual environments of increasing difficulty to train children in skills for driving wheelchairs. The first two worlds were safe, entertaining situations, designed to encourage skills necessary for independent mobility (e.g. independent exploration, cause and effect relationships). The third world aimed to build on the skills developed in the first scenarios, through exploration of a community environment, with increasingly complex situations to deal with. The authors place an emphasis on the students' motivation, ensuring that the scenarios are made fun where possible. The children's driving skills (particularly turning, stopping before hitting a wall and travelling in a straight line) improved with time spent on training in the virtual world. The authors also note that many of the children chose to look at a large monitor in front of them rather than using the head-mounted display. Although this decreased their degree of immersion in the virtual worlds, it did not decrease the children's interest in using the system.

Desbonnet et al (1998) describe the non-immersive Virtual Reality Training System (VRTS) for disabled children. To maximise the usefulness of the simulator as a training tool, users were able to navigate the virtual environment using the controller fitted to their chair. The authors concluded from these preliminary investigations that the VR wheelchair bore a reasonable resemblance in look and feel to a real chair but that the system was of limited value as a training tool due to the limited visual realism and the relatively crude modelling of the behaviour of the wheelchair. This study highlighted the need to address both these factors when developing virtual environments intended to assist in training powered wheelchair users.

In order to function independently in a powered wheelchair, an individual must attain a high level of manoeuvrability and dexterity but they must also demonstrate an ability to find their way around the locations they will visit in their chair (e.g. locations within an in-patient rehabilitation unit). Research has shown the value of exploration of virtual environments in learning about their real life equivalents with able-bodied samples (e.g. Brooks et al, 1999; Ruddle et al, 1997) and learning disabled samples (e.g. Wilson, Foreman & Tlauka, 1996). Work has also begun to address VR training of route-finding problems in neurologically impaired individuals. For example, Brooks et al (1999) found evidence of the efficacy of non-immersive VR in route learning for a patient, MT, with amnesia within a hospital rehabilitation unit. Following daily VR training sessions over three weeks duration, MT was able to perform a series of trained routes in the real unit. This continued to be true for another six weeks after training had ended, suggesting that knowledge gained in a virtual environment can transfer to real life. This study adopted an errorless learning approach to route finding training. Evidence has shown that learning is facilitated by preventing errors during training and such an approach is of benefit for those undergoing rehabilitation and learning new skills (e.g. Graf and Schacter, 1985; Rizzo et al, 1997; Wilson et al, 1994).

The current study seeks to address the efficacy of virtual reality in training adults with severe neurological impairment to improve their ability to use their powered wheelchairs independently. The study is concerned with two aspects of training. Manoeuvrability and dexterity skills are addressed through using a series of virtual tasks repeated over trials with feedback and performance review. Route-finding training is assessed using a separate virtual environment that represents a section of the hospital in which the patients are resident. Route-learning is facilitated by using an errorless learning paradigm adopting a series of computer-generated visual and auditory cues. Carry-over of skills is addressed in real-life settings following training. Qualitative and quantitative data is provided from an able-bodied sample (rehabilitation therapists), a sample of experienced powered wheelchair users and from initial training sessions with novice chair users or those requiring 'top-up' training. The study is a multi-stage project. There are three main stages involving able-bodied users, experienced powered wheelchair users and novice powered wheelchair users. Within each stage there are also different sections of the procedure. The stages and sections of the project are as follows:

Stage One: Able-bodied users exploring training and hospital environments

Stage Two (A): Experienced users performing manoeuvrability tasks in real life

Stage Two (B): Experienced users performing manoeuvrability tasks in VR

Stage Two (C): Experienced users exploring the hospital environment

Stage Three (A): Novice users performing manoeuvrability tasks in real life

Stage Three (B): Novice users being trained on manoeuvrability tasks in VR

Stage Three (C): Novice users performing manoeuvrability tasks in real life

Stage Three (D): Novice users being trained in route finding tasks in VR

Stage Three (E): Novice users being assessed in route finding in real life

2. STAGE ONE - ABLE BODIED USERS

2.1 Stage One Participants.

Ten able-bodied members of staff at the Royal Hospital for Neuro-disability volunteered to take part in this part of the study. Of these, four were qualified Occupational Therapists, four were qualified Physiotherapists, and two were Physiotherapy Assistants. Participants had between nine months and ten years experience of working in neurological rehabilitation (mean = 3 years 10 months) and varying amounts of experience of assessing and working with powered wheelchair users, from "none yet" to ten years.

2.2 Stage One Equipment.

Two non-immersive virtual environments were constructed using Superscape VRT software (Version 5.6) and ran on a Pentium III 550Mhz desktop computer with a 17 inch monitor. During this stage participants controlled their movement in the environments using a standard PC games joystick. Two virtual environments were developed, the first represented a single large room (known as the Assembly Room) in the Hospital. A series of chairs and tables were set up in the virtual environment to provide manoeuvrability tasks. The manoeuvrability tasks were as follows:

a) Driving the wheelchair forward in a straight line for 10 metres.
b) Reversing the wheelchair in a straight line for 2 metres.
c) Driving the wheelchair into an enclosed space.
d) Reversing the wheelchair back out of the enclosed space.
e) Completing a 180° turn around a stationary object.
f) Completing a 'slalom' around a series of stationary objects.
g) Stopping the wheelchair suddenly, to command.

A second virtual environment represented one floor of one wing of the hospital, comprising a large rehabilitation ward with a day area, four large four bed bays, four single bedrooms and a sitting room. Four treatment areas were also represented, comprising an individual therapy room, a computer therapy room, an art therapy room and an occupational therapy kitchen. The environment also included substantial lengths of corridors and a concourse area used by the patients and their families for relaxing and socialising. Signage and wall decorations were represented by incorporating digital photos. The environment included several walking people dressed to look like hospital staff and many stationary people seated in wheelchairs. At this stage of the project the moving people walked in a random manner.

2.3 Stage One Procedure

Sessions lasted approximately 30 minutes. Initially the joystick control of the virtual wheelchair was described and each participant completed a set of tasks in the 'virtual training environment' in order to gain an impression of the movement and responsiveness of the virtual wheelchair system. Participants were encouraged to make comments as they used the environment and were asked to give verbal feedback when the set of tasks had been completed. Participants were then introduced to the second virtual environment, to be used for route-finding training with experimental participants. They completed a set route which involved visiting each location in the environment in turn (e.g. sitting room, therapy room, computer room, art room). Having reached the final location, participants were asked to follow the route in reverse order. All participants were then asked to complete a short feedback questionnaire concerning a number of aspects regarding the virtual environment, including objects, colours, scale and movement.

2.4 Stage One Results

Feedback was collected using anonymous written questionnaires and recording verbal comments. The two virtual environments received a favourable response from the sample of therapists with regards to aspects of colour, perspective and level of detail with a mean rating of between 3.8 and 3.9 for each (1 = not at all well represented, 5 = very well represented). However, the computer-generated people in the main hospital environment, and the movement of the wheelchair were noted as particular limitations of the system receiving a mean rating of 2.6 and 3.1 respectively. These issues became the focus of development prior to the second stage of the study. Qualitatively, two participants suggested that the virtual environments could be beneficial if used as an adjunct to the training normally provided by Occupational Therapists. It was suggested that the system could be used to identify potential problems whilst waiting for a powered wheelchair.

3. STAGE TWO - EXPERIENCED USERS

3.1 Stage Two Participants.

Ten powered wheelchair users from the Royal Hospital for Neuro-disability volunteered to take part in this part of the study. Participants were selected on the basis of their high level of experience and skill in using their powered wheelchair. This selection was made by the research team, in conjunction with an Occupational Therapist. Six participants had had their powered wheelchairs for over ten years, three had had them for between five and ten years and one for less than five. All participants provided informed consent to take part in the project. Medical approval was obtained from the responsible senior physician in the hospital. Each participant completed one session in real life lasting approximately 30 minutes and one session using the virtual environments lasting approximately 45 minutes. The two sessions took place within 2-7 weeks of one another.

3.2 Stage Two Equipment.

The two virtual environments were as described in section 2.2 with further development on walking people (people now followed pre-programmed paths) and more accurately modelled wheelchair movement. The real-life 'training environment' was set out in the real Assembly Room using chairs and tables. The room and layout were the same for all participants. The doors to the room were closed so that there was no noise or distraction from outside. The only people in the room were the participant and two investigators. Participants used their own powered wheelchairs to complete the manoeuvrability tasks in real life. For the virtual environments they sat in their own chairs and used a wheelchair joystick connected to the computer via a PC wheelchair converter unit which was designed and made specifically for this study. If possible, their own joystick was connected to the computer. Otherwise, a similar wheelchair joystick was connected and was fixed to the participant's chair in the same position as their usual one. At this stage of the project it was not possible to develop converter interfaces to allow all possible makes of wheelchair controller to be used with the virtual environments.

3.3 Stage Two (A) Procedure: Completion of manoeuvrability tasks in real life.

Participants used their own powered wheelchairs to complete a series of driving tasks around a real-life environment. These were the same tasks as those to completed by the same participants later (in virtual reality) and by the able-bodied participants (virtual reality). The following performance measures were taken: time taken to complete each task; number of separate manoeuvres needed to complete a task; number of collisions during each task; distance travelled during each task.

A sensor and four magnets were attached to one back wheel of the wheelchair and a digital counter displayed the number of quarter revolutions of the wheel, allowing measurement of the distance travelled for each task. As wheel size varied between individual chairs, the circumference of the wheel was checked for each participant to allow precise measurement of distance. Time to complete each task was measured using a stopwatch. At the end of the real-life manoeuvring tasks, participants completed a short feedback questionnaire, conducted as an interview.

3.4 Stage Two (B) Procedure: Completion of manoeuvrability tasks in Virtual Reality.

In the first part of the session the VR training environment was presented. Before starting on the manoeuvrability tasks, participants were given a short time to practice using the wheelchair joystick to control their movement in the virtual world. Following this, the tasks described earlier were completed. On completion of the six tasks, participants completed a short feedback questionnaire (conducted as an interview) based on the questions asked about the real life tasks.

3.5 Stage Two (C) Procedure: Exploration of Larger Hospital Virtual Environment.

Participants were then introduced to the virtual hospital and asked to complete a predetermined route around the hospital. As for the able-bodied volunteers, the route began in the main room of the ward and involved visiting each main location in turn. Having reached the final point, participants were asked to follow the route in reverse order and were given the opportunity to explore the environment further if they wished. At the end of the session, participants completed another short feedback questionnaire with questions based on those on the able-bodied questionnaire.

3.6 Stage Two Results

3.6.1 Time taken to complete tasks. Comparisons between virtual reality and real life proved problematic because it was not possible to set the virtual wheelchair to the same speed as each individual's real wheelchair. However, for all ten participants, the total time taken for the six tasks was greater in virtual reality than in real life. For all tasks, the mean time taken in VR was greater than in real life. There were some exceptions, where individual participants were quicker in VR. Two participants were quicker on Task 1 (Forward), three were quicker on Task 2 (Reverse) and two were quicker on Task 4 (Reverse out of gap). The tasks that appear to have the largest difference between real life and VR are driving into the gap, the 180º turn around the table and the slalom. These are the three tasks where it could be argued that the considerable fine control is required to avoid collisions and therefore also where any differences between the real life and VR joystick will be most evident.

3.6.2 Distance travelled to complete a task. Distance travelled was measured in real life and VR for tasks 1, 2 and 6 to look at deviation from a straight line (Forward and Reverse) and at how close to the chairs participants stayed on the slalom. Difficulties were encountered in measuring distance travelled in real-life. The system of magnets to record revolutions of the wheel proved logistically unreliable and therefore data is not presented from these participants.

3.6.3 Collisions. There were a total of 4 collisions for all participants for all tasks in real life and a total of 140 collisions in the virtual environment. The largest numbers of collisions occurred for the tasks involving turning and obstacles, i.e. turning into the gap (26), the 180º turn around the table (57) and the slalom (46) in VR. These are much increased from the real life figures and could be explained by a number of factors including that the speed of the virtual wheelchair may have been set higher and thus made tighter manoeuvres more difficult to perform accurately. Unfamiliarity with the controls may also have had the same effect. The discrepancy between number of collisions between real-life and virtual reality may be explained by differences in the set-up of the joystick and movement (sensitivity, acceleration etc) from participants' real wheelchairs and the unfamiliar medium of virtual reality.

3.6.4 Number of separate manoeuvres. Participants generally used only one manoeuvre for each task in real life. In the virtual environment, the mean number of manoeuvres used was higher for all tasks. This was most noticeable on the three tasks involving turning and obstacles, i.e. turning into the gap, the 180º turn around the table and the slalom.

3.6.5 Tasks found easiest and most difficult. Reversing and the slalom were the most frequently selected as most difficult in both real-life and virtual settings. In real life, reversing is difficult since a real powered wheelchair will not immediately reverse in a straight line because of the front castors coming round into line whilst in VR reversing is hard because of the lack of peripheral vision. The slalom requires a considerable amount of fine control and dexterity. Driving forward in a straight line was the task chosen by the most people as being the easiest task in both settings.

3.6.6 Feedback comparing real life and VR training environments. After using the virtual training environment, participants were asked to compare how they found the tasks in the two environments (1=much easier, 5= much harder). A mean rating of 4.1 was given (range 3-5), showing that all participants found the tasks the same or more difficult in the virtual environment.

Participants were asked if they thought that the driving tasks were representative of the skills needed to drive a powered wheelchair and whether there were any relevant tasks missing. Six participants replied that the tasks were representative. Suggestions for additional tasks included: a three-point turn; uphill and downhill; unexpected obstacles (e.g. people walking out in front of the wheelchair); more straight line driving; some tighter obstacles; reversing into a gap as well as driving in; and having an open space to use prior to doing the course.

Most participants made additional comments when asked about driving the virtual wheelchair. Several participants commented on the lack of peripheral vision in VR and the implications this had for positioning themselves in the world. The joystick was generally thought to be quite difficult to control and quite different from what participants were used to, although most commented that the controls would get easier with practice.

3.6.7 Results from questionnaires about main virtual hospital environment. Aspects of the virtual environment such as colour, perspective, level of detail and scale of objects received acceptable mean ratings of between 3.8 and 4.4 (1 = not at all well represented, 5 = very well represented). Computer-simulated people and movement of the virtual wheelchair received lower ratings, of 3.0 and 2.9 respectively. This follows the same pattern as the able-bodied study. Further refinements of these aspects of the environments became a development priority following this stage of the study.

4. STAGE THREE - INEXPERIENCED USERS

4.1 Stage Three Equipment

The two virtual environments were used with further developments to wheelchair behaviour and walking people. People could now be stopped by the experimenter, so that the wheelchair driver could manoeuvre around them while they were stationary. A series of fading cues and prompts was added to the hospital environment to allow an errorless learning procedure to be followed for route learning. Participants used powered wheelchairs from the hospitals loan assessment stock.

4.2 Stage Three Procedure

Procedures varied slightly between participants depending on their circumstances, see individual sections for details. In general participants were asked to complete the manoeuvrability tasks in real life and then in virtual reality. They will then receive further training in virtual reality until they reach predetermined criteria on the training tasks. Following this, they will use the virtual hospital environment to learn a series of routes between the different locations using the errorless learning techniques. When they can complete routes within the virtual environment they will then be tested on those routes in real life.

4.3 Participant One - "CD" - Preliminary Results

CD is a 20yr old male who suffered a traumatic brain injury following an assault and has mild cognitive impairments. He had not used a powered wheelchair before taking part in the study. He practised for a few minutes prior to performing the six real life tasks in order to gain familiarity with the controls. He then performed the six real life manoeuvrability tasks according to the study protocol. Feedback was gained using a structured questionnaire. Two days later CD was introduced to the virtual training environment. A wheelchair joystick was attached to his manual chair and connected to the computer as in the previous stage of the project. As before, the participant had a few minutes prior to performing the tasks to get used to the controls. The same six tasks were then performed in the virtual environment. Following this, questionnaire feedback was obtained.

CD reported that the real life experience was "fun" whilst the VR experience was "a lot harder". Having completed both sessions, he said that real life was "better" and "easier". He found the 180° turn the most difficult task in both environments. In real life, he reported that the slalom was the easiest task, whilst in VR he reported that reversing in a straight line was easiest. This anecdotal feedback is reflected in performance measures. CD took longer to complete the virtual tasks, he travelled further, made more collisions and a greater number of separate manoeuvres. This confirms the impression provided by the experienced powered wheelchair users. The participant is currently taking part in conventional powered wheelchair training with an Occupational Therapist, after which he will be re-assessed on both the virtual and real-life manoeuvrability tasks.

4.4 Participant Two - "RS" - Preliminary Results

RS is an older male patient who had started conventional powered wheelchair training some time ago but was found to be easily distracted whilst driving. The training had therefore been discontinued. As described above, the participant performed the six manoeuvrability tasks in real life and then four days later performed the same tasks in the virtual environment. As with participant CD, on his first virtual reality training session, RS took longer to complete the tasks, travelled further and made more collisions when compared to real-life. VR training sessions were then commenced on a daily basis. During the training session the participant was asked to complete each task in sequence whilst receiving coaching and constructive feedback regarding aspects of their performance from the experimenter. Due to the participant's distractibility, the six tasks are generally only run through once per session. At the time of writing, the participant had performed the tasks in the virtual environment a total of ten times. His performance varied day-to-day and appeared to be related to tiredness and distractibility. Over the sessions, it was found that the participant benefited from regular reminders to remain focused on the task and to take each task slowly and progress in small movements.

4.5 Participant Three - "PB" - Preliminary Results

PB is a young female patient who had begun conventional powered wheelchair training with an Occupational Therapist. The participant has almost no expressive language and has moderate receptive language impairment. As for the other participants, she performed the six tasks in real life and then in VR a few days later. PB's performance on the virtual tasks generally conformed to that seen in the previous participants with regards to time taken, distance travelled, collisions made and separate manoeuvres. There was more variability in PB's performance however, such that when reversing out of the gap, she was quicker and made no collisions in the virtual environment and when reversing in a straight line she needed considerably less manoeuvres to complete the task.

VR training sessions then commenced on a daily basis. Generally, the six tasks are run through twice in a half-hour session. At the time of writing, the participant had performed the tasks in the virtual environment a total of ten times. Her performance has varied slightly between sessions, possibly related to tiredness. She performs the tasks relatively quickly and has perfected three of the tasks, although this is not consistent across sessions. Due to PB's receptive language impairment, she benefits from having the route required for each task pointed out on the monitor and, for the longer and more complex tasks, having this broken down into small steps.

5. DISCUSSION

The current study aims to provide both qualitative and quantitative data regarding the development of two non-immersive virtual environments for the training of powered wheelchair users. Results to date indicate that for able-bodied participants, experienced powered wheelchair users and one novice user, the simulated wheelchair and training system received favourable responses regarding colour, depth/perspective, scale, look of objects and level of detail. The representation of simulated people in the environment received a less favourable rating, as did the movement of the virtual wheelchair, both aspects were subsequently developed during the study.

Qualitative and quantitative data from participants indicated that whilst the virtual environments were considered realistic and well represented, and the tasks represented the skills needed to manoeuvre a powered wheelchair, completing manoeuvrability tasks was generally more challenging than in real-life. For the experienced powered wheelchair users this increased difficulty may represent the novelty of using a virtual system compared to the real powered wheelchair, however initial data from a complete novice produced a similar differential. In addition, differences in the responsiveness of the virtual wheelchair and issues regarding the validity, reliability and sensitivity of the performance measures used in the study require further consideration. These issues have implications for the sensitivity of virtual environments as a training tool in this context. Whilst it may be expected that the virtual system proves initially more challenging due to its novelty, the size of the difference must not be so great as to de-motivate the user or to prove overly challenging and thereby limit carry-over of skills into real-life. On-going training sessions will shed further light on whether the high level of difficulty experienced in the virtual environments represents an initial 'teething' stage or persists throughout the training period.

A number of difficulties were encountered in measuring performance in both virtual and real-life. The number of collisions made during individual tasks and the number of separate manoeuvres made during a task appeared to be sensitive measures of performance. Other performance measures, such as time taken and distance travelled, proved logistically difficult to measure with sufficient accuracy and may represent a range of confounding factors (e.g. reaction time and speed of the virtual wheelchair relative of the real powered wheelchair, behaviour of the virtual wheelchair compared to the real powered wheelchair when reversing) which would not be considered as representing an individual's skill in using the wheelchair. Developing a system of measurement and recording which accurately reflects skilled performance remains crucial in order to critically evaluate training outcome and improve training methods.

Several experienced chair users noted that the lack of peripheral vision was a problem when using the simulated chair. This particularly affected the participants' ability to check to the side and behind when reversing but may also have affected their ability to adjust their position relative to the stationary objects in the slalom task. This remains a limitation of non-immersive virtual simulations at present and requires particular consideration and development for applications in the field of wheelchair training.

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Session II. Interfacing to Virtual Environments I

Chair: John Wann

Using haptic feedback to enhance computer interaction for motion-impaired users

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ABSTRACT

For users with motion impairments, the standard keyboard and mouse arrangement for computer access often presents problems. Other approaches have to be adopted to overcome this. There is evidence to suggest that increasing the degrees-of-freedom, and hence bandwidth, of human-computer interaction (HCI), can improve interaction rates if implemented carefully. Haptic feedback is not really exploited in the existing HCI paradigm, so offers a potential method for broadening the interaction bandwidth by complementing the existing interaction structure. This paper describes a series of pilot studies to assess the effectiveness of two possible methods for incorporating haptic feedback into the interaction. The aim was firstly to ascertain whether the motion-impaired could detect the feedback successfully and then to assess whether the feedback may be of benefit. Two experiments were performed, one to test vibrotactile feedback and the other force feedback. The vibrotactile results were inconclusive, but the force feedback results were very positive.

1. INTRODUCTION

Computers can be a source of tremendous benefit to those with motion impairments (Busby, 1997). They offer greater freedom to participate in education and leisure activities, as well as increased job potential and satisfaction. For example, the ability to operate a word processor, spreadsheet and database is often sufficient to perform many useful administration tasks.

Users with a number of different motion impairment conditions cannot cope with most current computer access systems. Such conditions include athetoid, ataxic and spastic Cerebral Palsy, Muscular Dystrophy, Friedrich's Ataxia, Tetraplegia and spinal injuries or disorder. Frequent symptoms include tremor, spasm, poor co-ordination, restricted movement, and reduced muscle strength. Similar symptoms are also seen amongst the elderly able-bodied population from conditions such as Parkinson's Disease, strokes and arthritis. Any computer input system intended for use by people with varying physical capabilities and designed around one method of input is unlikely to be flexible enough to cope with the diverse needs and demands of the users satisfactorily. This is not to say that it might not suffice, but for extended computer usage something more flexible and with a broader bandwidth may be required.

This idea is supported by evidence that suggests increasing the degrees-of-freedom of input devices, such as incorporating finger flexion, can improve interaction rates (Zhai, 1996). Extending this principle to include more degrees-of-freedom through multiple input channels, implies that this should also yield improved information transfer rates. However, increased degrees-of-freedom in the interaction can actually increase cognitive workload if not structured carefully (Keates and Robinson, 1999). To maximise the usefulness of the additional interaction modes, it is necessary to for those modes to complement and support the existing ones.

The existing keyboard/mouse/monitor paradigm relies principally on visual feedback, often supported by sound. The use of haptic feedback is restricted to the physical interaction with the specific input device, such as feeling the mouse or touch-typing, but is under-utilised. In the current graphical user interface (GUI) paradigm, icons and windows are directly manipulated but there is no resulting touch (tactile) or feel (kinaesthesic) feedback to the manipulating limbs. This lack of *articulatory feedback* (Hix and Hartson, 1993) makes the interaction more difficult and suggests a new potential carrier channel for information. The human "feel" sense actually consists of three main senses, which are difficult to distinguish. The tactile perception system receives its information through the various *cutaneous* sensitivities of the skin. However, *kinaesthesia* or "body sense" also results from the operation of mechanoreceptors that are sensitive to forces in the skin, muscles, tendons and joints, and these are interpreted in conjunction with knowledge of efference or outgoing motor signals, visual feedback and muscle stretch receptors. Hence, kinaesthesia, is the awareness of movement, position and orientation of parts of the human body. *Haptic perception* is the active gathering of information about objects outside of the body through the tactile and kinaesthetic senses. The tactile, kinaesthetic and haptic sensations can be considered together as *tactual perception* (Loomis and Leederman, 1986).

Motion-impaired users often exhibit decreased motor control and muscle strength, but not necessarily a decreased sensitivity of touch. Consequently, if haptic feedback can be successfully incorporated into the interaction paradigm, then these users may be able to benefit from the enhanced feedback from using both touch (tactual) and feel (kinaesthesic) interaction.

There are two ways in which the use of haptic feedback may enhance the usability of interfaces for the motion-impaired. It may be possible to enrich the standard user interface with haptic textures, bumps and edges in order to signal the location of windows, buttons and regions as the mouse passes over them. This is predominantly a touch directed channel. In addition it is possible to use force-feedback within the input device to present constant forces, and tactual and vibration sensations corresponding to user interface events. This force-feedback mode has the capability of boosting or aiding user input in the case of muscle weakness and damping or restraining user inputs, in the case of muscle spasm or tremor. The sensitivity of motion-impaired and able-bodied users to haptic feedback has been demonstrated using devices such as the Phantom (SensAble, 2000). However, this is an expensive research tool that is unlikely to be used routinely as a general-purpose interaction device.

The vibrotactile feedback in the following experiments was generated using the Max/MSP graphical programming environment (Dobrian, 1995) on an Apple Macintosh. This environment was originally developed for electronic music and multimedia applications and as a result has good real time capabilities. It has been applied to the acquisition and processing of interaction data (Vertegaal, 1998). It uses signal processing capabilities to generate low frequency audio signals related to cursor position. These were transmitted to the user via the input device through the use of electro-mechanical drivers, such as loudspeakers.

Force feedback has recently been used to haptically enhance action games using joysticks such as those made by Microsoft and Logitech. Its implementation is based on the industry standard I-Force protocol for haptic feedback devised by the Immersion Corporation (Immersion, 1999). This protocol describes a library of haptic sensations usable for games such as explosions, inertia and friction, blows and shudders, as an extension of DirectX under MS Windows. This technology can also be applied for general user interface purposes and it is currently marketed by Immersion, in an extended form for desktop applications, as TouchSense. The first non-experimental device on the market to use this extended protocol is the Logitech force-feedback mouse used in this research. This device is, in principle, capable of generating both tactual and force-feedback haptic interactions with the user as a result of its very wide range of movement generation capabilities.

This paper describes trials carried out with motion-impaired users at the Papworth Trust using vibrotactile and force feedback in tasks representative of the standard User Interface. The principal research question at this stage, is whether haptic feedback can be of any benefit in the computer interaction for motion-impaired users. There are a number of specific experimental questions:

(1) Can motion-impaired users perceive tactual feedback?
(2) What is the sensitivity of motion-impaired and able-bodied users to vibrotactile and force feedback?
(3) Can haptic feedback be used to enhance motion-impaired users' ability to use standard interfaces?

2. EXPERIMENTS

2.1 Introduction and General Aim

Three experiments were designed as pilot studies to examine the feasibility of using haptic feedback systems for motion-impaired users. The users were all residents of the Papworth Trust (Cambridge, UK), a charitable organisation dedicated to the care of the motion-impaired, and are detailed in Table 1.

The first experiment involved exposing motion-impaired users to a restricted range of vibrotactile feedback. This range, in terms of spatial frequency of stimuli, amplitude and frequency of vibration, was chosen to cover the range of able-bodied haptic capabilities derived from previous experience with these devices. There were three vibrotactile feedback mechanical actuators (1) a small loudspeaker stuck on a standard PC mouse, in contact with the thumb or one of the user's fingers (2) a medium sized loudspeaker held under the fingers of the non-mouse manipulating hand; (3) a powerful low-frequency driver mounted on a wooden plate below the mouse-pad that vibrated the whole mouse contact area. The users' sensitivity was measured as the quality of sensations and detection rates.

The second experiment used the sensitivity information from the first to present a systematic and controlled set of haptic stimuli, varying the parameters described above, with the intention of investigating quantitative properties of sensitivity, such as threshold. The users' sensitivity was measured in terms of detection rates.

Table 1. *Motion-impaired users from the Papworth Trust*

User	Description
PV1	Athetoid Cerebral Palsy, spasm, wheelchair user
PV2	Friedrich's Ataxia constant tremor, wheelchair user
PV3	Athetoid Cerebral Palsy, ambulant
PV4	Athetoid Cerebral Palsy, deaf, non-speaking, ambulant
PV5	Athetoid Cerebral Palsy, wheelchair user

The third experiment used the force feedback technology developed by Immersion in the form of a mouse input device. This device was used to provide force-feedback assistance in location of a number of pointing targets of varying degrees of distance and size, provided in an immersion demonstration program. The users' performance was measured as time to complete a number of pointing actions, and error rates, with and without force-feedback assistance.

2.2 Experiment 1: Vibrotactile feedback pilot

2.2.1 Method. The motion-impaired users were presented with a task of detecting stimulus elements that were accompanied by vibrotactile haptic feedback. The stimuli represented an array of vertical lines on the screen and the users were effectively feeling when the cursor crossed one of the lines. Their detection rates were measured for a range of physical parameters: stimulus amplitude; and mechanical actuator (speaker) position and type. The stimuli were set manually by the experimenter during the trials and the data recorded by hand. In order to prevent auditory emanations from the large vibrotactile actuators providing cues to the users as to the detectability of the stimuli, a sound signal was sent to a second medium sized sound speaker, irrespective of the stimulus. The intention was that the users' would not then be aware of whether the sound accompanied a detectable stimulus.

2.2.2 Apparatus. An Apple Macintosh PowerBook G3 is used, running a Max program for generating the stimuli. The user had a separate monitor (VGA 640x480 pixels) and mouse, both connected to the same computer. The experimenter used the keyboard, trackpad and screen of the PowerBook to control the experiment. A standard USB mouse was used and the button functions were disabled. The users were free to select their preferred hand for operating the mouse.

Three actuators were used: a small loudspeaker positioned on the mouse and under the user's fingers or thumb; a medium sized loudspeaker, held under the fingers of the non-mouse hand, and a low-frequency driver, mounted on a wooden plate below the mouse pad, vibrating the whole mouse contact area. The audio output level of the Mac was set to maximum, and an external amplifier was used to drive the actuators. Only one of the two available channels was used for this experiment. The small speaker was a CPC KDS-2008, O.lW 8.Q, 019.8mm, with the speaker edge filed off to reduce the height of the speaker from 4.0mm to 3.0mm cone. The medium speaker was a Sony SRS-28 active mini loudspeakers: O.4W, 8.Q, 065.5mm, height 14.3mm. The low-frequency driver was a loudspeaker without a cone by Aura, 87.1mm in diameter, attached to the bottom of a wooden plate resting on rubber silencing blocks.

2.2.3 Task. The users were asked whether they could feel any sensations from the speaker as they moved the mouse cursor over a pattern of vertical lines. Stimuli of different frequencies and amplitudes were generated for each trial. The users were asked to report whether they had detected any haptic sensation. This was done orally by saying "yes" or "no".

2.2.4 Stimuli. The stimuli generated by the computer were variable in amplitude, wavelength (and hence frequency) and spatial distribution of the virtual pattern. It was emphasised to the users that one of the amplitude settings being used was 0, i.e. no power, to avoid any possible concern if no sensations were being discerned. Table 2 shows the full range of stimulus parameters used.

The stimuli were generated by three different actuators; these were the three speakers described above. In addition, the Aura driver was used on two different volume levels of the external amplifier. The base frequency of the stimulus was chosen to be 25 Hz or 83.33 Hz so as to avoid as the auditory sensitivity range and minimise the audibility of the haptic device in operation.

Table 2. *Stimulus parameter levels.*

Amplitude (% of maximum)	0, 30, 60, 100 %
Waveform	Triangular
Spatial frequency Distribution (line spacing / pixels)	1, 2, 4 Pixels
Frequency (Hz)	25Hz, 83.3 Hz

The virtual stimulus generated when each line was crossed by the cursor was an impulse, or delta-function. For the physical stimulus generated, this was approximated by a triangular waveform. As this was a pilot study to test whether the users could discern any sensations, it was decided not to vary the waveform, although sine and square waves were possible alternatives. Figure 2 shows a representative output from one of the speakers. Each peak corresponds to an impulse being generated as the mouse cursor crosses a line.

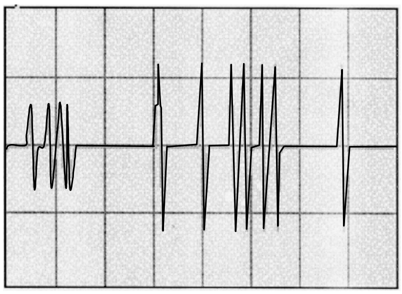

Figure 1 *Waveform resulting from cursor movement: 30% amplitude levels on the left hand side and 60% on the right.*

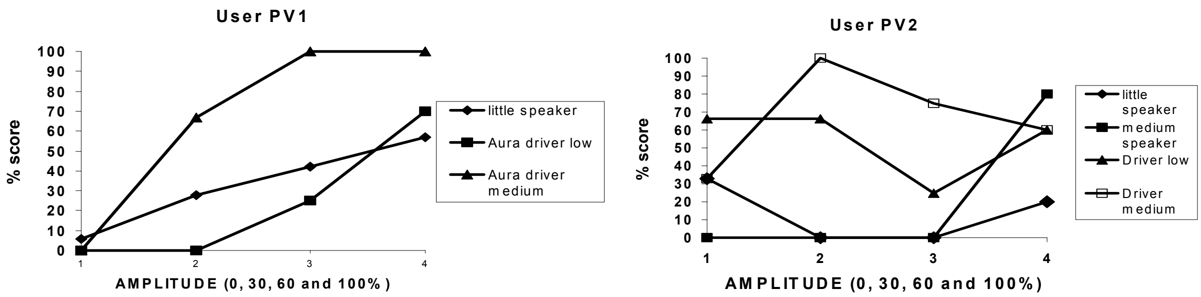

Figure 2a & 2b. *Users PV1 and PV2 detection scores for different amplitudes and actuators*

2.2.5 Results. The data recorded was entered into a spreadsheet program for analysis, plotting and descriptive statistics. The number of false positives at the 0% amplitude level gives a qualitative guide to the reliability of the results from a particular user. However it does not provide an absolute quantified measurement, as it is only an indicator of the user being able to identify that *no* output is being generated. It does not provide a guide to how well a user can determine that an output *is* being generated. That is indicated by the remaining values in the graph.

User PV1 performed the task using the small speaker and the large Aura driver at high and medium output levels. From Figure2a it can be seen that PV1 had a relatively low number of false positives at the zero amplitude level for all three actuator types. However, only the Aura driver on high power, with larger amplitudes of stimulus produce results near the 100% recognition rate. All of the other results can be explained away as chance because of the $p = 0.5$ likelihood of guessing a correct answer and the low number of samples taken ($N<5$). Consequently, the results are generally inconclusive about PV1's ability to discern the vibrotactile output. User PV2 used the same speakers as PV1, with the addition of the medium speaker providing a fourth actuator type. Figure 2b shows the results observed from this user. There is a high level of false positives across most of the actuator types, indicating a difficulty discerning the stimuli. This is supported by the results for the non-zero amplitude settings, which appear to be random in nature.

User PV3's performance indicated high sensitivity. There were no false positives at 0% amplitude and consistent 100% recognition rates for all the high amplitude variations of stimuli spatial frequency, and actuator type, suggested that this user was widely sensitive to vibrotactile haptic stimuli. Consequently, the tasks were repeated with a wider range of stimuli for this user to assess whether his capability was uniformly good across more different conditions. These included changing the spatial frequency distribution, how far apart the line stimuli were. The 30% amplitude stimuli showed some differentiation between conditions. For the small speaker, the sparse, low frequency stimuli were poorest, and the fine spatial frequency stimuli better. However, the medium speaker stimuli were detected at low and high frequencies. Interestingly, when the user was instructed to apply pressure to the small speaker in gripping the mouse, effectively squashing the output, the detection rate fell to chance levels.

The pattern of results suggest that the users' ability to perceive the haptic stimuli depended on the extent of their ability to grip and position the mouse and actuator. Hence, PV2, who has to resist tremor and grip the mouse using the middle finger joints, was not sensitive to the vibrational stimuli. However, PV1, who had comparable sensitivity and manipulation skill to able-bodied users, showed high levels of sensitivity. The results from PV3 were close to chance and the presence of some false positives suggests that they may be inconclusive.

2.3 Experiment 2: Vibrotactile feedback: initial results

The second experiment used the same experimental set-up, but with systematic variation of amplitude, stimulus frequency, and spatial frequency within a range suggested by the pilot experiment. Again the motion-impaired users were presented with a task of detecting stimulus elements accompanied by vibrotactile feedback, effectively 'feeling' a pattern of vertical lines. The detection rates were measured for a range of physical parameters: spatial frequency (i.e. line separation); stimulus amplitude; and mechanical actuator type and position. To reduce order effects and the effect of improvement with practice, a full randomised design was employed, with all 24 combinations resulting from varying the parameters amplitude, frequency, and spatial distribution on the levels as described in Table 1 above. The actuator position was varied to achieve maximum effect under the user's direction. To minimise the effects of auditory pollution, a second speaker was used in conjunction with the larger speakers to provide masking noise. This arrangement proved partially successful in achieving this, making the sound output less obvious, although not removing it completely.

2.3.1 Results. User PV2 again generated a large number of false positives for 0% amplitude conditions. In addition the results were distributed around chance for the small speaker. The large Aura driver, however, positioned underneath the non-mouse hand or the mouse platform, appeared to give rise to an increased number of positive detections in the high amplitude conditions and reduced occurrence of false positives. This may have been due to auditory detection of the speaker in operation.

User PV3 again performed almost perfectly for both small and medium speakers, with all stimulus conditions.

User PV4's detection levels were around chance for the small speaker, with some false positives. However, interestingly, detection levels improved for the large driver, over all conditions. This is interesting, as the deafness of this user prevented the hearing of possible auditory cues to stimuli that could underlie other users performance. The user reported a strong tactile sensation for the large driver.

2.3.2 Discussion. As before, the pattern of results suggest that users' abilities to perceive the haptic stimuli depended on the extent of their ability to grip and position the mouse and actuator. The inclusion of the deaf user PV4 was revealing in that his good result in the large speaker driver condition could not have been due to auditory cues and so he was definitely experiencing and discerning the vibrotactile sensations.

2.4 Experiment 3: Force-feedback

In this experiment the ability of a force feedback device to assist both motion-impaired and able-bodied users in a typical GUI pointing task was investigated. The users were presented with a simple GUI pointing task on a standard PC and the times to complete the task with and without force feedback assistance for differing levels of difficulty were recorded. The error rates from missed clicks was also recorded.

2.4.1 Method. Four motion-impaired and two able-bodied users were presented with the Immersion Corp's Connect-the-dots development, sample computer application. The program recorded the time taken to complete a sequence of point and click tasks, where the targets were distributed in a fixed, irregular pattern across the screen. Each target consisted of two concentric circles. The green coloured inner circle was the actual target to be activated by clicking on it. The blue outer circle indicated the extent of the force feedback locus of attraction, or gravity well, around the target. Positioning the cursor within the blue circle resulted in a spring force towards the green target circle. This task was repeated both with and without the force feedback active. Four motion-impaired users from those described in Table 1 participated in this experiment. The able-bodied users were University Research Associates.

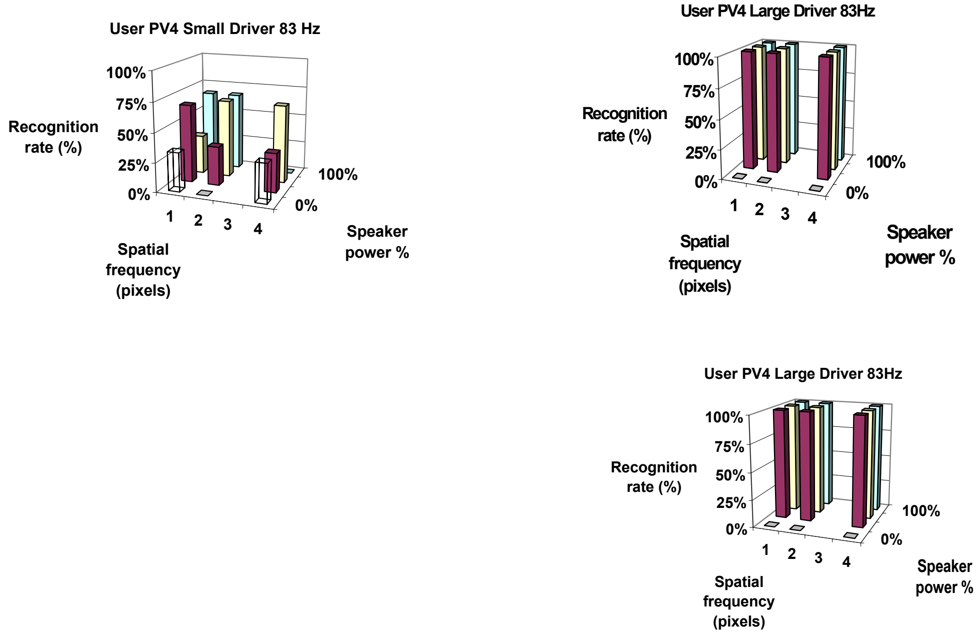

Figure 3. *Typical rates for spatial frequency and speaker power for the vibrotactile drivers at two frequencies.*

2.4.2 Task & Stimuli. A 2D flattened projection map of North America was drawn on the screen and the 10 target locations were distributed as fixed city locations on this map. The targets consisted of two concentric circles where the outer circle was of constant diameter and filled with the colour blue. The inner circles radii differed in the difficulty conditions, with the hardest condition having the smallest diameter circle. The inner circles were coloured green. After the start signal was displayed, the user was required to move to, and click on, the inner circle of the target circle whose outer circle area was flashing. Successfully clicking on the centre circle immediately initiated flashing of the next target in the sequence. On completion of the required sequence of targets, the timer was stopped and the number of clicks outside of the target circle (misses) displayed. The elapsed time, and start and stop signals were displayed at the top of the screen. During the force-feedback trials the Immersion "WingMan" mouse was strongly attracted to the centre of the target once the outer circle was reached. During the unaided mouse trials the interface behaved as a normal point and click mouse. The program forced a complete training set on the identical stimuli before each force-feedback trial. The users performed the task using the easy, medium and hard settings and the time data recorded after each trial.

Table 3. *Time to complete trials with and without force-feedback for all users (average errors in brackets).*

		PV2	**PV5**	**PV1**	**PV3**	**AB1**	**AB2**
Easy	**WITH FF**	49.5 (2.4)	8.7 (0.4)	41.6 (2.0)	12.4 (0.0)	6.4 (0.0)	6.4 (0.0)
	NO FF	-	19.0 (2.8)	79.9 (10.4)	20.0 (3.0)	9.5 (1.0)	9.5 (1.0)
Med.	**WITH FF**	74.2 (4.4)	9.8 (1.0)	36.5 (1.2)	11.3 (0.4)	7.0 (0.0)	7.0 (0.0)
	NO FF	-	25.8 (2.6)	-	20.3 (1.4)	11.3 (1.4)	11.3(1.4)
Hard	**WITH FF**	-	11.8 (1.6)	-	12.2 (0.6)	8.0 (0.4)	8.0 (0.4)
	NO FF	-	24.3 (2.4)	-	21.5 (0.4)	15.7 (1.4)	15.7(1.4)

2.4.3 Results. There was a considerable improvement in both time to complete trials and error rates with the force-feedback. Typical performances were exemplified by two users. User PV2 was unable to perform the task in the unassisted mode taking as long as 364 seconds in one trial to complete half the targets on the easy setting. However this user was able to perform five trials using the force-feedback assistance, showing a substantial learning effect for the task over trials. A consistent number of 2 missed clicks for each set of 10 targets was recorded. This pattern was repeated for the two harder sets of trials although the average time to complete each set increased. User PV5 was able to perform the unassisted interface task, showing an average completion time of around 20 seconds. However, scores were substantially improved during the force-feedback assisted trials, at around half that time on average. This effect occurred for the two harder sets of trials. There was evidence of a learning effect across trials and tasks.

2.4.4 Discussion. A strong positive effect of force-feedback was observed for both motion-impaired and able-bodied users. In particular, the times to complete the trials were reduced by 30–50% of times for normal interaction modes. The improvement that occurred was so marked that motion-impaired users were, in some cases, able to equal and exceed the performance level of the able-bodied users, most noticeably in the higher difficulty settings. The error rates, as indicated by the number of missed clicks, were of uncertain origin. This was due to the lack of knowledge of the application's internal criteria for a missed click.

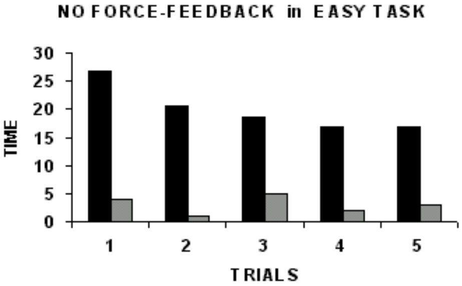

Figure 4. *Easy task trial times without (left) and with (right) force-feedback for user PV3. Grey bars are number of errors.*

A strong learning effect can be inferred across trials and across conditions. This was not unexpected as the position and order of the stimuli remained constant throughout the experiment. However, it would be expected that practice with both the force-feedback and unassisted mode of pointing would also lead to improvement for randomised orders. This remains to be tested. Clearly, a number of weaknesses of this experiment lie in the use of a development demonstrator application. This includes the lack of randomisation of distance, size and location of the stimulus targets. In addition the visual implication of the differing areas flashing borders for targets is not quantified. Finally the training trials before each force-feedback trial set is asymmetrical with the unassisted interaction modes, although it could be argued that the users have already received extensive practice in unassisted mouse pointing tasks in everyday use of PCs. The strengths of the experiment include the realism of the task and resemblance to standard GUI interactions; the use of a natural input mode in the form of a mouse and force-feedback assisted mouse; the interesting nature of the task when compared with other tedious experimental manipulations, especially for motion-impaired users.

3. GENERAL DISCUSSION

Overall the results from the vibrotactile haptic feedback are not conclusive. For the particular implementation used here, that of positioning a speaker driven by a sound signal underneath the users hand or fingers, it appears that the feedback is useful only to the most capable. In particular, the pattern of results from the vibrotactile experiments suggests that user ability to perceive the vibrotactile stimuli was affected by the extent of their motor capability to grip and position the mouse and actuator. Feedback was not available to those who gripped the mouse in a non-standard way or to those who were forced to exert damping movements to counteract tremor or spasms. However, this is not taken to suggest that vibrotactile haptic feedback aimed at stimulating the cutaneous receptors is not useful, just that this method of channelling vibration forces may not be effective. In addition, some users were able to prevent the small speaker from operating by applying force, consciously and unconsciously. This has also been observed in some able-bodied users who involuntarily contract their fingers when performing normal clicking movements, preventing the speaker from operating.

The inclusion of PV4, who was deaf, suggested that a good result for the large speaker driver may not have been due to auditory cues. However, this result is not conclusive because the user was physically more capable than a number of the other users and there was a general inverse correlation between physical capability and ability to discern the stimuli. It is worth noting that the Logitech force-feedback mouse is capable of generating forces conveying fine textures and grids and that, in addition, these forces possessed a directional component. The normal operation of this device is accompanied by minimally audible sounds that could be easily deadened or masked. Future experiments will assess the use of this device for implementing vibrotactile feedback.

The deficiencies of the experimental conditions in the vibrotactile experiments suggest that undue emphasis should not be placed on small differences within the results for the users. These deficiencies include: the use of incomplete conditions; the non-quantified learning effect over trials; the unknown effects of grip and actuator positioning; the effects of inadequate sound masking for the larger devices; the use of a narrow and incomplete range of waveforms and base vibration frequencies; and the influence of the good user role. Despite this, it was clear that users showed evidence of being sensitive to the stimuli in various vibrotactile conditions and that this was broadly correlated with their degree of impairment.

The results from the force-feedback trials strongly suggest that this method of haptically enhancing interaction with the GUI could be of great benefit to both motion-impaired and able-bodied users. An advantage of this approach that emerged from the use of the device is that it is capable of delivering both vibrotactile forces, affecting the touch, cutaneous senses and also forces of greater magnitude that can stimulate the kinaesthesic system receptors. It is capable of delivering direction and magnitude information in a mode of operation that is very similar to that of a normal mouse. Future experiments will focus on changing the properties of the locus of attraction round each target to establish optimal sizes and force feedback profiles.

4. CONCLUSIONS

Of the experimental set-ups investigated in this paper, the force feedback mouse appears to be superior to the vibrotactile speaker feedback for the enhancement of motion-impaired user interactions with GUI's. The pronounced improvements in point and click activity performance by all users suggests that force feedback devices, such as the WingMan mouse, are cost-effective methods for improving the interaction of motion-impaired users with user interfaces. Although the degree of enhancement provided by the vibrotactile feedback appeared to be inversely proportional to the degree of disability, the force feedback appeared to benefit all users and, if anything, to be of greater use to the more impaired.

In addition, there was a suggestion of reduced error rates with force-feedback and no observed evidence of increased cognitive load resulting from the introduction of haptic information. These conclusions will be tested with more rigorous experimental testing of the two types of feedback. Evidence was obtained to suggest that the vibrotactile technique may enhance interaction, but this certainly needs to be investigated further. If the correlation between capability and ability to discern the vibrotactile sensations is proven, then this may only be of limited use for more severely impaired users. Further research is also needed to establish the device positioning and stimulus properties needed to exploit this technique to maximum effect.

Acknowledgement. The authors would like to thank the staff and users at the Papworth Trust for their participation in the user trials and Mr A J Bongers for providing the experimental set-up and gathering the data for the vibrotactile experiments.

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Basic issues concerning visually impaired people's use of haptic displays

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ABSTRACT

Haptic displays present a potential solution to the old problem of rendering pictorial information about 3D aspects of an object or scene to people with vision problems. The aim of the paper is to discuss some basic issues of importance for the usefulness of these displays for visually impaired people: (1) The overview of a virtual object or scene available for exploration with only one point at a time, (2) The limited spatial resolution of haptics, (3) The potential effects of learning, (4) The necessity of simplifying pictorial information, (5) The enhancement of tactile information with auditory and visual information.

1. INTRODUCTION

Until recently, people with severe problems in reading visual pictures have been restricted in getting pictorial information about three-dimensional (3D) scenes to real 3D models or tactile pictures in two dimensions (2D). However, real models are rare and expensive, and reading 3D aspects of 2D tactile pictures is a difficult task (Jansson, 1988). Haptic displays presenting virtual 3D scenes mean a fascinating potential opportunity for people with severe vision problems to get information equivalent to what sighted people get from pictures (Jansson, 1999a). However, there are complications. The design of visual displays from a human perception point of view has been rather extensively investigated (Tullis, 1997) and there is a growing research about how to utilise audition for auditory displays (Gaver, 1997), but similar studies on haptic displays have only started.

In most applications of haptic displays they are used as enhancement of visual (and sometimes auditory) information. A haptic display without an accompanying visual display is not very common, but is the only option for a person with severe vision problems. This is a situation very different from a situation with both visual and haptic displays available, as haptics is normally co-operating with vision. The aim of this paper is to discuss some basic issues concerning the use of haptic displays when the information they provide is not supported by visual information. The discussion is concentrated on one of the leading commercially available haptic displays, the PHANToM (Sensable Technologies, Inc.), but it ought, to a large extent, to be applicable also to other haptic displays.

2. OVERVIEW OF AN OBJECT OR A SCENE BY EXPLORATION

Vision presents a (nearly) immediate overview of a scene or object, but haptics usually does not. The closest haptic analogue to a visual overview may be a grasp of an object with many simultaneous points of contacts between object and hand, but normally you get the overview only successively. An object is typically explored by manipulating it with several fingers changing their positions in relation both to the object and relative to themselves. This exploration is as basic for haptics as eye movements for vision, and there are a large variety of exploration methods (Lederman & Klatzky, 1987).

The restricted overview for haptics is to a large extent compensated for when vision is available as well. Vision provides a general overview and can guide haptic exploration by suggesting locations to be explored haptically and by supervising the movements of the relevant body part to these locations. This means that the use of a haptic display together with a visual screen may not suffer too much from the haptic lack of overview. The situation without vision is dramatically different. It is easy to miss significant properties of an object or scene and even the presence of objects. This general restriction of haptics is accentuated when there is only one contact point at a time between observer and virtual object, as is the case with the three-degrees-of-freedom PHANToM. (The new six-degrees-of-freedom device is an improvement from this perspective, but the difference to natural haptics is still large.)

In an experiment the performance with restriction to one point of contact, as with two 1.5 PHANToM options (stylus and thimble), was compared with the performance with corresponding real objects explored naturally (Jansson & Billberger, 1999; Jansson, 1999b). The natural condition allowed all potentials of natural exploration, including the use of several fingers and unlimited skin surface. This means that any differences in performance do not depend on the one-point-of-contact aspect but on other factors as well. The result demonstrates to what extent PHANToM exploration utilises the potentials of natural haptics.

The dependent variables in the experiment were proportion of correct judgements of the form of simple geometric objects and the time used for exploration. The performance with the two virtual conditions differed dramatically from the performance in the real condition. The real objects were always judged correctly in a few seconds, while the virtual objects were judged less correctly after a longer exploration time (Figure 1). This difference in results can hardly be attributed to differences in physical properties. The virtual objects mirrored the real ones quite well, possibly with the exception of sharp borders not being exactly similar. The main aspects separating the real and the virtual conditions seem to be those related to the exploration properties. When several points of contacts are available, as in natural exploration of real objects, the observer gets a rapid overview of the object (at least with objects of the sizes studied) which makes a correct judgement in a few seconds possible.

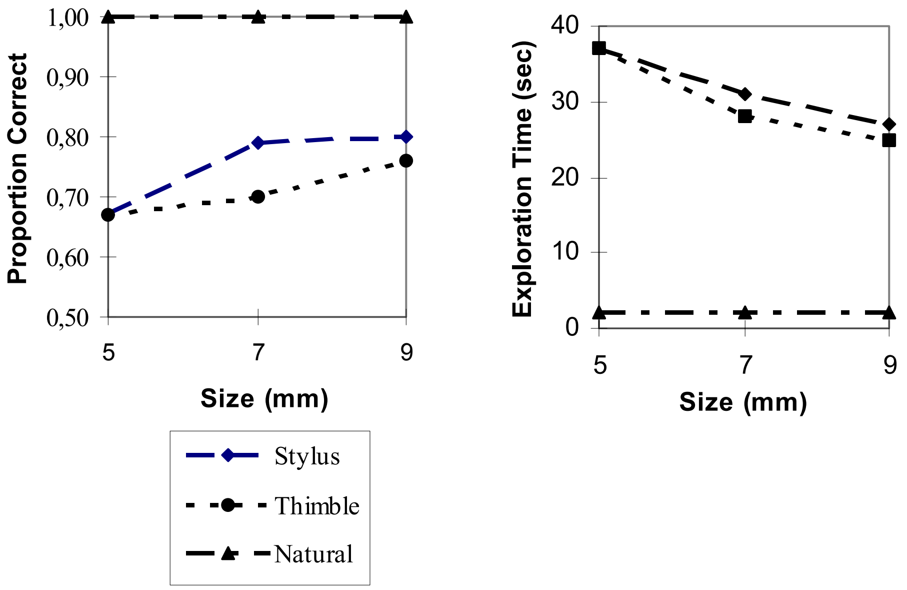

Figure 1. *Exploration time and proportion correct judgements as a function of exploration method and object size (Jansson & Billberger, 1999).*

It should also be observed that the results for the two PHANToM options were very similar. This was not expected, as the two options engage a different number of contact points between the hand and the device; the stylus is held by several fingers (similar to a pen), while only one finger is used with the thimble. This difference does not seem to be significant, however. The result indicates that the important difference in the performance between real and virtual objects is the common character of the latter: that the objects are explored with only one point at a time. This prevents a maximum utilisation of haptic perception.

One possibility to facilitate the user's exploration along a contour or over a surface is to use "magnetic" attraction (Fänger, 1999; Sjöström, 1999). This makes it easier to avoid loosing track with the feature being followed, thus being useful for the integration of the feature. Sjöström also suggested that it is useful, in order to favour exploration, to modify sharp edges by evening them out.

3. SPATIAL RESOLUTION

It can not be generally stated that a haptic display such as the PHANToM presents properties of virtual objects that can not be as effectively judged as those of real objects. It has been shown experimentally that virtual textures explored with a stylus-equipped PHANToM are judged very similar to corresponding real textures explored in the same way (Jansson et al. 1999). However, when it concerns judgements of form the proportions of correct judgements about virtual objects are lower and the exploration times longer than for real objects judged by natural haptics as reviewed above.

3.1 The Percentage of Correct Judgements of Form and Exploration Time as a Function of Size of Object

It is reasonable to expect that the size of an object has effects on both the correctness of judgements about its form and the time it takes to explore it. However, it is not self-evident what effects to expect. It may take more time to explore a large object than a small one if the exploration is straightforward, but the decision about the form of a small object may be more difficult than that for a large one because of limitations of tactile acuity and uncertainty motivating prolonged exploration. In two experiments the ability of observers to identify the form of objects in two different size ranges was investigated. In one of them (Jansson et al., 1999) the object sizes, in terms of maximum length in each dimension, varied between 10 and 100 mm, and in the other (Jansson & Billberger, 1999) they were in the range of 5-9. The observer's task in both experiments was to judge the form of virtual objects in different sizes and simple geometric forms explored with a 1.5 PHANToM stylus.

In Figure 2 the results are combined. For the larger objects (10-100 mm) it was found that the percentages of correct judgements were not very far from 100 % and that the exploration times of the largest objects were around 15 sec. For the smaller objects (5-9 mm) the percentages were lower and the exploration times longer. The results demonstrate that observers can make judgements above chance level (25 %) also for objects as small as 5 mm, but that the percentage increases only slowly with size being clearly below 100 % also for much larger objects. Apparently it has reached an asymptotic level less than 100 % at the size of 50 mm. At the same object size an asymptote for exploration time at 15 sec is also indicated.

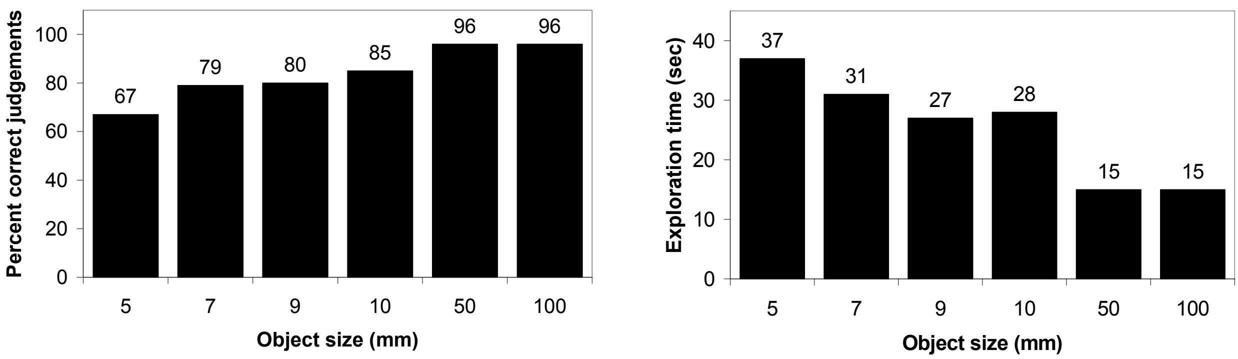

Figure 2. *Percent Correct Judgements and Exploration Time as a function of Object Size (See text for explanation).*

These results demonstrate that within the size range studied the percentage of correct judgements increases and exploration time decreases with object size. However, even if an asymptote is indicated within this range it can not be excluded that an extended range would have some kind of U-form, as it is unavoidable that it take more time to explore very large objects and that the integration of information over their surface may be more difficult. It should also be noted that the asymptote levels are far from what haptics can achieve with real objects explored naturally.

4. POTENTIAL EFFECTS OF LEARNING

The natural ways of exploring real objects have a long history of learning, both biologically and individually. The observers in the experiments just reviewed had no experience in using the special exploration methods of the PHANToM before the experiment. It can be assumed that their experience of similar methods in real life was also quite restricted, if they had any such experience at all. It is reasonable to assume that the results obtained in the experiments would be improved if the observers were given the opportunity to learn to use them. However, large differences both between users and for a user over time can be expected.

That there are differences between novices and experts in the use of computer-based devices is generally known, and there has also been research concerning a more basic understanding of what functions are involved (Mayer, 1997). One probably very important function, not the least in the case of haptics, is exploration skill. There are several reasons to believe that the development of skills of this kind is important for the functioning of interaction between display and user (Gibson, 1979; Pejtersen & Rasmussen, 1997). A possibility that may be applicable to a haptic display such as the PHANToM is that it requires a special skill of exploration which varies quite a lot between users and that is not very well developed at the start of using the device. However, it may develop rather rapidly if there is some basis in related natural and/or well learned other movements

4.1 Can the Performance with a Haptic Display be Increased by Short-Time Learning?

The main aim of an experiment by Jansson & Ivås (2000) was to investigate if performance can improve already after short-term learning of identification with the PHANToM of the form of objects. Secondary aims were to get some preliminary hints on the possibility of some exploration methods being more effective than other methods are. The participants explored with the stylus option of a 1.5 PHANToM nine blocks of 24 objects distributed over three different days. Percentage of correct identifications and exploration times were measured. The exploratory behaviour of the observers was also videotaped in order to find out if there were any differences between spontaneous exploration methods used by successful and less successful observers, and if the observers changed exploration method during the learning.

The result was that there were large individual differences between the observers, but a majority among them increased significantly their percentage of correct identifications; in fact, the mean percentage in this group was doubled from the first to the third day. However, exploration times decreased only slightly. The minority group did not show any improvement of percentage correct judgements and had in general results only slightly above chance level. The main conclusion that can be drawn is that the percentage of correct identifications can, for many observers, be increased by spontaneous learning over a few days.

No differences in exploration method could be found between successful and less successful observers, nor between different days for the successful observers. However, it should again be noted that also after this learning the performance with virtual objects was far from the performance with real objects explored naturally.

5. THE NECESSITY OF SIMPLIFYING PICTORIAL INFORMATION FOR HAPTIC READING

It can not be excluded that a user of a haptic display will reach a very high level of performance after long-term learning. The results reviewed above indicate, however, that a novice has usually a limited capability of using such a device. Even if performance for many users can be improved already after short-term learning, the problems of haptics to get en overview and to identify detailed information make it necessary to modify originally visual information when presented for haptics in order to make it sufficiently useful.

This has for a long time been known concerning the production of 2D tactile pictures from visual originals (Edman, 1992; Eriksson, 1998). In most cases such pictures are manually modified on the basis of practical experience with the goal to make them more readable for people with vision problems. To make this professionally is a time-consuming and therefore expensive undertaking that reduces the amount of pictures made available for visually impaired people.

An early effort to use numerical image analysis for this task was made by Pun (1982). More recently, Michel (1999) discussed the possibilities of individual tactile maps and analysed possible simplifications of digital maps for tactile presentations. It is a huge task already to continue the development of such analyses for tactile maps and other 2D representations, and a still more complex assignment to do this work for 3D representations, such as virtual objects and scenes presented via haptic displays. The solutions hoped for may contain automatic procedures and/or possibilities for the user to accomplish modifications by simple commands, such as simplifications (e.g., deletion of some kinds of information) and useful distortions (e.g., enlargement of difficult parts of a route map at the sacrifice of easier parts). Without the development of procedures of this kind, the enormous amount of pictorial information on the net will not be available for people with severe vision problems, even if they have a haptic display at hand.

6. ENHANCEMENT OF TACTILE INFORMATION WITH AUDITORY AND VISUAL INFORMATION

6.1 Enhancing by Audition

That multimodal information is advantageous in many contexts is well known. It is reasonable to assume that the restrictions of haptics in some respects when haptic displays are used can, at least partly, be remedied by adding auditory information. This has been demonstrated in other technical aids for the visually impaired. Pioneering work to combine auditory information with tactile information was made by Parkes (1988) for 2D tactile pictures placed on a touch tablet. More recently, efforts to make multimodal programs where haptic displays are enhanced by auditory information to be used by people with vision problems have been made for architectural models (Fänger, 1999; Weber, 2000) and for computer games (Sjöström & Rassmus-Gröhn, 1999). Verbal information, for instance, can contribute to the user's getting an overview of the scene and to finding relevant parts of it for detailed exploration. Not only verbal information may be useful, but also other kinds of auditory information may be quite advantageous, for instance everyday sounds strengthening the perception of the identity of an object (Gaver, 1997).

6.2 Enhancing by Residual Vision

Visually impaired people are usually not totally blind but have some residual vision that can be useful under specific conditions. If it is possible to benefit from such residuals in the context of haptic displays does not seem to have been studied so far. However, it is extensively used in hard-copy tactile pictures, for instance, by the use of colour that simplifies the task of reading pictures for many people with vision problems. A difficulty in general implementation of such enhancement is the large variety of residual vision, which means that the arrangements have to be adapted to the functioning of each individual's remaining sight.

Such arrangements can of course be tried in the so far most common situation with visual and haptic displays not being spatially co-ordinated, which means that there are separate perceived visual and haptic spaces. However, the recent development of a device with co-ordinated such spaces (ReachIn Technologies AB) provides an interesting option also for people with vision problems. To investigate the usefulness of such an arrangement for visually impaired people would be a most interesting undertaking. However, one problem for its application to all people with residual vision is that it is based on binocular vision which many of these people have not available.

7. CONCLUSIONS

The fascinating options provided by the haptic displays to solve the classical problem of providing the visually impaired with pictorial information, especially about 3D aspects, has to be investigated both from the point of view of possibilities and the point of view of limitations. Some issues important for both facilitating and aggravating aspects of these devices were reviewed here. It is yet too early to draw definitive conclusions about the usefulness of haptic displays for visually impaired people.

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Haptic virtual environments for blind people: further explorations with the Phantom device

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ABSTRACT

The development of force feedback devices to add haptic information to virtual environments (VEs) has important implications for both able-bodied and disabled computer users. A study is presented in which blind and sighted participants used a PHANToM 1.0 force feedback device to feel a range of virtual grooved textures using both a thimble and stylus interaction device. Although there was no significant difference between blind and sighted participants, there were individual differences in the way the textures were perceived which have important implications for the use of haptic information in VEs. The stylus was found to produce more sensitive perception of the textures than the thimble, for both blind and participants.

1. INTRODUCTION

The development of force feedback devices to add haptic information to virtual environments (VEs) has important implications for both able-bodied and disabled computer users. Haptic information is the combination of what we feel through our skin (cutaneous information) and what we feel through the position and movement of our limbs and joints (kinesthetic information) (Loomis and Lederman, 1986). For able-bodied VE users, haptic information will undoubtedly add to the overall realism of the environment . But for blind people, the possibility of providing haptic information in VEs is extremely exciting. VEs which consist of haptic and auditory information have many useful and entertaining applications for blind people.

At the last conference in this series, two papers from different research groups (Colwell et al, 1998; Jansson, 1998) reported on preliminary investigations of the perception of virtual haptic information using the Impulse Engine 3000 and the PHANToM 1.5A force feedback devices respectively. Both these papers reported research which found that sighted and, in the case of the work by Colwell et al., blind participants could perceive haptic information using these devices. The studies investigated the perception of virtual textures (sandpaper like textures by Jansson and grooved textures by Colwell et al), and the identification of virtual objects and their sizes and angles of their surfaces.

One question which arises repeatedly about this type of research is whether the perceptual effects found thus far are specific to the particular devices and force feedback algorithms being used, or whether they are general to all simulations of haptic information? Unfortunately the two papers presented at the last conference did not investigate the exactly same effects, so although they used two different force feedback devices, they could not provide comparative information on this question. Some key aspects of the technical specifications for the two devices are shown in Table 1. The devices also use different algorithms for calculating the appropriate force feedback to apply at any instant and all these differences could affect the perception of virtual stimuli.

The current research has therefore extended the work undertaken with the Impulse 3000 by Colwell et al (1998) by using a PHANToM 1.0 force feedback device, in order to investigate whether perception of virtual textures and objects is similar when experienced via a different device. We have also investigated the effect of using different methods of interaction with the PHANToM device, either using a thimble (see 1) or a stylus (see Figure 2).

Table 1. *Some key aspects of the technical specifications of Impulse Engine 3000 and PHANToM 1.0.*

	Impulse Engine 3000	**PHANToM 1.0**
Workspace size	13 x 23 x 23 cm	13 x 18 x 25 cm
Maximum exertable force	9.0 Newtons	8.5 Newtons
Nominal position resolution	.023 mm	.030 mm

In the current paper, the focus will be on the perception of virtual texture, implemented as a simulation of a surface with fine grooves. Roughness of real surfaces has been studied extensively by psychologists using the psychophysical technique of magnitude estimation. This technique uses series of stimuli of known physical characteristics. Participants are asked to assign numbers to the roughness they perceive, so that if a stimulus seems twice as rough as another, it is given a number twice as large. Thus if a person calls an initial texture "20" then one which they perceive as twice as rough would be labelled "40" and one half as rough could be labelled "10". It is well known that perception of such stimuli produces a power law such that $R = P^n$, where R is the perceived Roughness as expressed by the magnitude estimate and P is some Physical characteristic of the surface such as grit size for sandpaper. n is known as the power law exponent. If this law holds then log (R) will be a linear function of log (P) with slope n. Such a law holds for many sensations including brightness of lights, loudness of sounds and heaviness of weights (see many perceptual psychology textbooks a fuller discussion, for example Snodgrass, Levy-Berger and Haydon, 1985). Stevens and Harris (1962) found that this law also held for roughness of sandpaper of varying grit sizes. Starting in the 1970's, Lederman and her colleagues used more controlled stimuli of grooved plates where they could independently manipulate various parameters of the grooves. They found a power law with a small positive exponent relating roughness to groove width; and a power law with a small negative exponent relating roughness to land width (space between the grooves). So wider groove widths lead to greater perceived roughness when land is constant, but wider land widths lead to lower perceived roughness when groove width is held constant.

2. METHOD

2.1 Design

The magnitude estimation technique was used to assess the perceived roughness of a set of virtual textures, identical in their characteristics to those used by Colwell et al (1998). A completely repeated measures design was used, with one group of participants feeling all the textures with both a thimble and a stylus interaction device attached to a PHANToM 1.0 force feedback device.

2.2 Participants

23 people took part in the study, 10 blind and 13 sighted, aged between 19 and 54 years, with a mean age of 46. The blind participants comprised two women and 8 men, 5 of whom where blind from blind, the remaining 5 having lost their sight between the ages of 8 and 42 years (this means they are all classified as being "late blind", having had sight, or some sight during their early development). The mean age of the blind participants was 46 years. None of the blind participants had any more that light/dark perception. These participants were recruited from the Sensory Disabilities Research Unit's subject pool. These participants were volunteers who were only paid travel expenses to come to the Sensory Disabilities Research Unit at the University of Hertfordshire.

The sighted participants, 7 women and 6 men, were all university students, from a variety of disciplines. Their mean age was 27 years (recalculate for the 13 appropriate participants please). These participants were also volunteers, although 7 psychology students received credit towards their research methods training for participation in the study.

2.3 Equipment and stimuli

The study was conducted using a PHANToM 1.0 force feedback device, run from a Pentium II 400 MHz PC with 64MB RAM (see Figures 1 and 2). A thimble interaction device (see Figure 1) and a stylus interaction device (Figure 2) were both used in the study. Throughout the experiment, participants heard white noise through a set of Sanyo PH 200N headphones, so they could not use any auditory cues from the PHANToM to assist in their judgements of the textures.

Figure 1. *The PHANToM 1.0 with thimble interaction device*

Figure 2. *The PHANToM 1.0 with stylus interaction device*

The stimuli were simulations of virtual textures of a sinusoidal pattern, all with an amplitude of .1125mm and with groove widths in 10 equal steps between .675 and 2.700mm (see Figure 3).

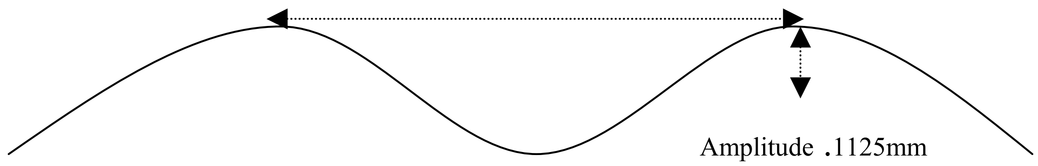

Figure 3. *Profile of grooved sinusoidal texture*

2.4 Procedure

Participants were given a brief introduction to haptic virtual reality and force feedback devices. The magnitude estimation technique to be used in the study was also explained to them. Participants were given one of the textures from the middle of the range to feel and asked to assign an initial, modulus number to it. All other textures were then scaled in relation to that modulus. Participants were given six examples of each of the 10 textures in random order, presented in blocks of 10 textures.

3. RESULTS

For each participant, the relationship between the "physical" characteristics of the virtual textures and their perception of those textures was investigated. The amount of variation in their magnitude estimations which could be accounted for by the characteristics of the textures is indicated by the adjusted r^2 values in Table 2, and the nature of the relationship between the texture characteristics and their perceptions of them is indicated by the exponent.

Table 2 shows that for the 13 sighted participants, 9 (69%) perceived a meaningful relationship between the different virtual textures using both the stylus and the thimble. Two participants (S6 and S10) perceived a meaningful relationship only using the thimble interaction device and one participant (S8) perceived a meaningful relationship on using the stylus interaction device. One participant (S12) failed to perceive the relationship with either interaction device. For the 10 blind participants, 9 (90%) perceived a meaningful relationship between the different virtual textures using both the stylus and the thimble. The remaining blind participant (B6) perceived a meaningful relationship only using the stylus.

However, although these differences are interesting for the comparison with the previous study using the Impulse Engine 3000, an analysis of variance showed that there was no overall difference in the perception of the textures by blind and sighted participants ($F_{1,22} = .66$, $p > .05$). There was a significant difference between the perception of the textures using the stylus and the thimble ($F_{1,22} = 7.31$, $p < .05$), with the mean exponent for the thimble being lower than that for the stylus, meaning that the thimble allowed less sensitivity of perception.

For the sighted participants, these results show that more people could detect the variations in the virtual textures with the PHANToM device than had been able to with the Impulse Engine 3000. Colwell et al (1998) found that only 7 out of 13 sighted participants (54%) could reliably detect the relationship between the virtual textures for the same set of textures (during the original analysis of the data from the Colwell et al study, it was discovered that there had been a error in the calibration of the Impulse, these figures reflect the re-analysis of the data with an appropriate correction factor), whereas the current study found the 69% perceived the relationship with both interaction devices, and 92% (12 out of 13 participants) perceived the relationship with one of the two interaction devices. For blind participants, results from both studies show that at least 90% of participants perceived a meaningful relationship for these textures.

Table 2. *Summary of results of magnitude estimations of virtual textures by blind and sighted participants.*

	Interaction Device					
	Stylus			Thimble		
	Adj. r^2	Exponent	p of exponent	Adj. r^2	Exponent	p of exponent
Participant						
Sighted						
1	.831	-.708	.0005[2]	.610	-.832	.005[2]
2	.865	-1.081	.0005	.953	-1.553	.0001
3	.655	-.774	.005	.581	-.470	.01
4	.797	-1.06	.0005	.869	-1.347	.0005
5	.557	-.585	.01	.910	-.887	.0001
6	.294	-.573	n.s.	.912	-1.538	.0001
7	.672	-.687	.005	.889	-.601	.0001
8	.716	-.696	.005	.143	-.237	n.s.
9	.647	-.646	.01	.805	-1.107	.0005
10	.190	-.352	n.s.	.601	-.560	.01
11	.388	-.389	.05	.338	-.381	.05
12	.088	-.036	n.s.	.070	.104	n.s.
13	.872	-.229	.0001	.972	-.592	.0001
Blind						
1	.751	-.827	.001	.895	-1.460	.0001
2	.845	-.420	.0005	.906	-.597	.0001
3	.584	-.446	.01	.877	-.700	.0001
4	.425	-.231	.05	.903	-1.486	.0001
5	.824	-.730	.0005	.859	-.846	.0005
6	.775	-.403	.001	.143	-.159	n.s.
7	.600	-.515	.01	.788	-.607	.0005
8	.913	.463	.0001	.928	.608	.0001
9	.688	-.514	.005	.889	-.766	.0001
10	.648	-.431	.005	.924	-.893	.0001

5. CONCLUSIONS

This study has shown that there are differences in the perception of virtual textures between two different force feedback devices. Given that these devices differ on a number of hardware and software parameters (see Table 1), we cannot say as yet which specific parameter might account for these differences. The results from the PHANToM device have replicated our finding from the Impulse 3000 that there are also substantial differences in the way different individuals perceive the roughness of different grooved textures. These results have important implications for the use of haptic information in VEs. For textures of the type studied here, one cannot predict how they will be perceived by different individuals. This might be particularly problematic if people are sharing a collaborative VE

It is also interesting that the thimble produced significantly less sensitive perceptions than the stylus. At a purely phenomenological level, one would have expected the opposite. The thimble seems to be a more direct way of feeling textures and objects, as one is feeling *through* the material of the thimble, whereas the stylus is less direct, as one is feeling along the stylus to the texture. However, it may be that because we are all very used to writing with stylus type devices, it is more natural to hold this device and use it as a perceptual tool as well as a writing tool. Again these results have important implications for the use of haptic information in VEs. If perception of fine-grained information such as texture is important, at the moment with the current technology, a stylus interaction device is preferable to a thimble one.

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Internet based manipulator telepresence

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ABSTRACT

A wheelchair based manipulator MANUS for severely handicapped people is in use with over one hundred people in their homes. Assessment, telepresence, training and communication among users and between users and professionals are helpful in many phases of acquisition and use of such a manipulator. Services and technologies are developed in the EU supported project Commanus (remote diagnosis, remote optimisation, and remote control). Internet communications with both real and virtual real functions are described in this paper.

1. INTRODUCTION

The MANUS[1] manipulator is a technically advanced robotic manipulator designed to be mounted on a wheelchair and able to assist severely handicapped users in their daily tasks. An example of a Manus manipulator mounted on a wheelchair is shown in Figure 1. Today we witness the tendency that Rehabilitation Robotics (RR) is gaining slowly acceptance among the handicapped community and only a fraction is actually using the robotic manipulator devices in their daily lives. The main reason is the availability of alternative solutions such as smart homes, human carers and assistants to do tasks or services that could otherwise be performed by rehabilitation robots. Another factor that limits the use is the relatively unawareness of the potential users and rehabilitation advisors of the real capabilities of the robots if they are aware of their existence at all. Even when this awareness is present it is still difficult to decide whether or not to purchase the rehabilitation robot. The decision is mainly driven by the expected practical value of the rehabilitation robot, expressed in the increased hours of independence, the perceived utility and the estimated cost savings. Usually, this requires a time consuming assessment involving a rehabilitation robot, a rehabilitation advisor and service of the manufacturer of the rehabilitation robot. The potential user has to prove to be able to control the robotic device using a suitable human machine interface. Therefore, apart from choosing the right interface, the handicapped user has to train and reach a certain skill level even to be considered for purchasing these relatively expensive devices.

Another limiting factor is the high service level of these devices, which poses problems to the manufacturers as they are usually SMEs (small- to medium-size enterprises) with limited resources for service and support. This is also a cost increasing factor. Taking into account these aforementioned factors, the cost reimbursement organisations are not convinced of the benefits of these rehabilitation robots. In addition they may be less familiar with the advances in these new technologies and therefore reluctant in purchasing robotic devices.

Related to the above mentioned aspects is the fact that, so far, no effective infrastructure to reach the end users and potentially new users is available. Therefore, there is a strong need to have a better understanding of the user and the user needs and to have a well-established dissemination of information to show the cases with successful robotic rehabilitation solutions. In other words, we have to bring the Research and Development and the user community together to bring the benefits of RR into practice.

This paper describes an Internet based environment to operate a virtual or a real robotic manipulator in which the technology is totally transparent to the user. Internet based robotics systems are to some extent already as state of the art available (Leifer et al, 1997), though not for commercial RR systems.

We propose 'telepresence' as a means for teleassessment, teletraining, teleeducation, telediagnosis and telemaintenance. In this paper we will first introduce the global architecture of the system and discuss the 'tele'-aspects one by one.

[1] Exact Dynamics, Product Information URL: *http://home-1.worldonline.nl/~dynamics/*

Figure 1. *Manus manipulator mounted on a wheelchair.*

2. SYSTEM ARCHITECTURE

In Figure 2 a simplified schematic sketch of the system architecture is presented. The set-up is based on and inspired by the developments in RETIMO (Dreissen & van Woerden, 1999) and in the COMMANUS project.

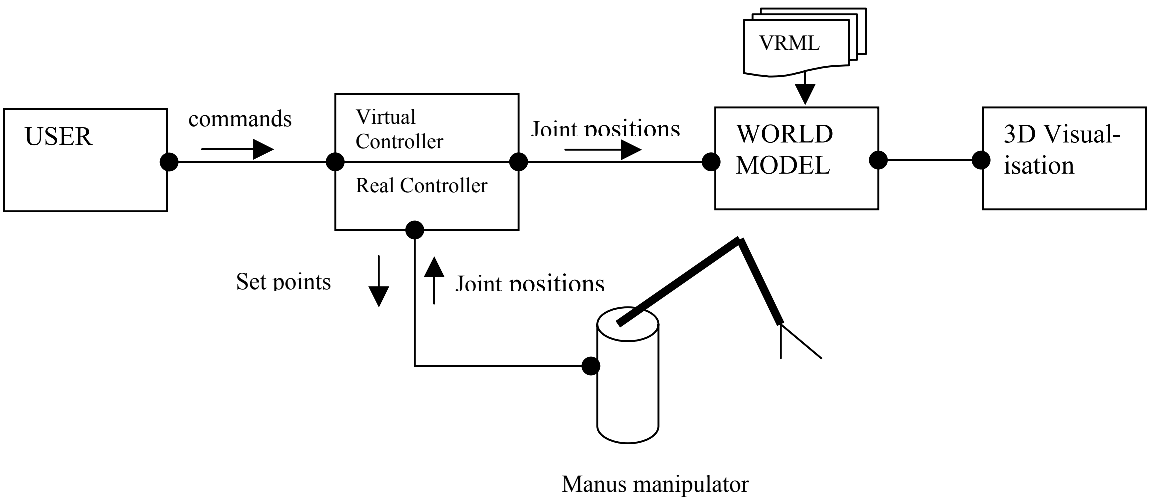

Figure 2. *Global architecture of the internet based manipulator telepresence environment.*

In this set-up the different building blocks are connected through the Internet as the means of communication whereas they may be at physically different locations. The user in Figure 2 can assume different roles. Typically, there are the handicapped user, the developer and the support and maintenance engineer, all using the same infrastructure. However for different types of use the blocks may be distributed differently over the real world. For example in remote assessment the handicapped user may control the real Manus manipulator through the Internet at a remote location relying only on a visual feedback.

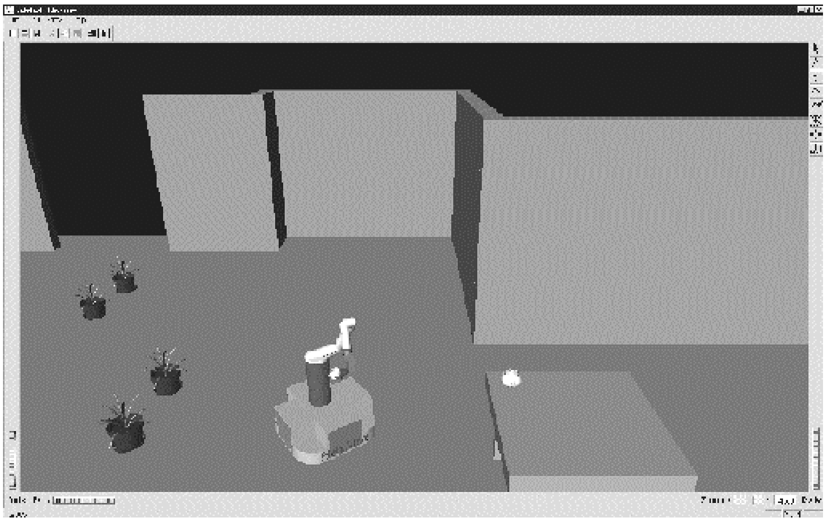

Figure 3. *A possible virtual world.*

The user chooses to use either the virtual controller or the real controller, which steers the real robotic device. In the world model different scenarios can be loaded which can range from complex scenes to mimic different real world situations to a simple scene with just a representation of the robot. The real world model is based on VRML file format, an emerging 3D-description standard, which is rich enough to ensure realistic visualisation as well as compact to facilitate responsive rendering through the Internet. An example of a virtual environment is shown in Figure 3. Currently, in the 3D-visualisation we use OpenInventor® as the 'glue' between the VRML input, the socket communication with the clients and the 3D rendering. This guarantees the developer a real-time performance and at the same time opens the way to generate VRML output.

3. TELEPRESENCE AND A VIRTUAL ENVIRONMENT

3.1. Virtual assessment

Users can perform first experiments over the Internet with a simulation environment like the one depicted in Figure 4.

With assistance over the net, either in text or by human speech, the disabled people can assess their ability to control simple movements. Moreover, they can mount the Manus manipulator in the virtual space on their own type of wheelchair and control Manus e.g. with a joystick.

3.2. (Tele)Training, Learning

A training and education module is under development, where a three-level training home is foreseen. The user environment consists of a control device connected to a web application (PC with Internet and access to the training site).

The training module consists of:

(a) A users home (later it may be the home of the disabled user) provided, at level 1, with only a Manus manipulator in the virtual space. In this environment the degrees of freedom of Manus can be controlled.

(b) At level 2 the manipulation of objects is trained in 2 ways. In the virtual space blocks (the well-known Kwee building blocks) can be mounted on top of each other either in a predefined or in a free setting.

(c) Use of the Manus manipulator in a virtual home is at the 3rd level. At this level the wheelchair with a Manus mounted on it can perform special tasks controlled by the user over the net. "Go from the living room to the kitchen. Open the door, drive trough the corridor. Open the kitchen door, go to the kitchen. Open the refrigerator, pick up a bottle of beer and return to the living room. Drink your beer."

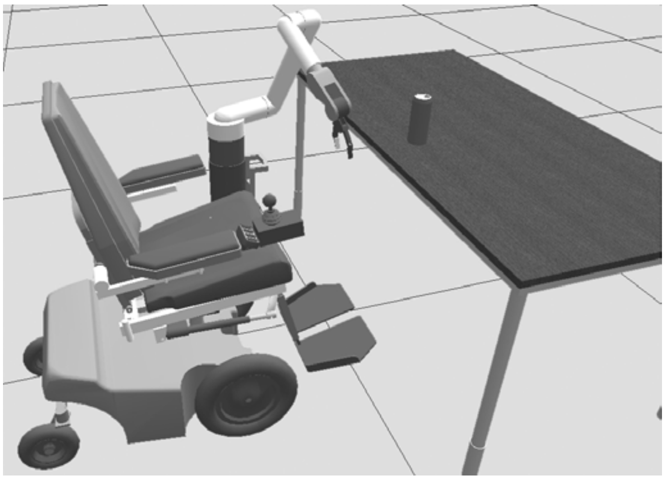

Figure 4. *A possible simulation scenario: working with a virtual manipulator.*

3.3. (Tele)Education

A Manus user and a professional assistive technology adviser are able to optimise functionality through communication with virtual reality and demonstrations in reality. Various users, communicating with each other can also perform this act.

3.4. (Tele)Diagnostic, Monitoring and Maintenance

By means of the Internet communication the user can be monitored and followed for health care purposes or to see whether service is required. It may also happen that the Manus is stuck in a certain position; in this case the embedded safety precautions, which prevent the user from damaging the Manus, make it impossible for the user to get it out of this position. In this particular situation, the support engineer remotely gets the current position and enters a lower control level to engage a safe trajectory to a correct position. Of course, the engineer may first practice a safe trajectory on a virtual robot to ensure a proper result. This procedure leads to a faster and less expensive maintenance and, for problems that can be solved via software, avoids the user to send the manipulator for service.

3.5. Virtual Development Environment

The virtual environment may help and boost research and development in new and efficient ways. First of all, the controller may be simulated and the effect of the new control can be visualised and validated in the virtual environment prior to testing it on the real robot.

Secondly, advanced controls such as an intelligent path planning algorithm for moving to a pre-defined position in a well-defined way from any point in the workspace can be developed off-line. Furthermore, the cost of development may be reduced as virtual robots are cost-effective solutions and several virtual robots can exist in parallel without extra costs.

Thirdly, a virtual developing environment opens the way to effectively integrate with other areas such as machine vision. Especially, a robotic device such as Manus with a substantial amount of backlash may benefit from feedback sensor equipment. This is essential if the Manus manipulator has to carry out tasks autonomously. One can envisage the Manus manipulator a task like "pick-up book", or "pick-up coffee cup". Semi-automating these tasks may enhance the usability and user-friendliness substantially.

4. FUTURE DEVELOPMENTS

4.1. RR Community

We foresee the development of a virtual rehabilitation robotics community. In this framework users can exchange recorded functionality, discuss best practices of control and exchanging self made operational modes like, for instance, a new drinking mode. Furthermore, in this community the interaction between users and professional will be essential and it will be encouraged, in order for the professionals to have a better understanding and view on required functionality.

4.2. Machine Vision Capabilities

One of our goals is to have Manus on a mobile base and carry out tasks autonomously. In order to do that, we are currently working on providing our system with machine vision capabilities. One or more cameras can be used for several and useful purposes.

A vision system in fact can be helpful for the navigation of the mobile base especially when working in an indoor environment. The robot may make use of natural or artificial landmarks present in the working space both for positioning itself and for target definition and path planning. From the manipulator point of view, which doesn't require help for positioning, a vision system is useful for helping the disabled user in tasks such as finding the object of interest, defining the best grasping point and speeding up the sequences of operations. An obstacle avoidance skill can improve performances both for navigation aspects with the mobile base and for safety aspects related to the manipulator.

From the point of view of the virtual environment development, a vision system is required for dealing with modified environments that have to be accurately rendered.

4.3. Improved Sensor System

New sensor systems will facilitate manipulation with Manus. An example is force/torque feedback sensors, which may help with complex tasks such as putting a cassette into a VCR. Experimentation with virtual sensors in the virtual environment will facilitate the design phase.

5. CONCLUSIONS

The assessment, training, learning, performance supervision, technical support and maintenance for rehabilitation robotic devices are difficult, expensive and insufficient supported for individual severe handicapped users. Since over one hundred Manus wheelchair mounted rehabilitation robots are now with users at their homes, the time is right for 'telepresence' as presented in this paper. We propose an infrastructure where the user, the developer and the support professional are brought together and may learn and benefit from each other. It is time to bring the benefits from Rehabilitation Robotics into practice. The Internet based manipulator telepresence environment will give a modest step forward in this direction.

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ICDVRAT 2000

Session III. Acoustic Virtual Environments

Chair: Tomohito Kuroda

Multi-sensory virtual environment for supporting blind persons' acquisition of spatial cognitive mapping, orientation, and mobility skills

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ABSTRACT

Mental mapping of spaces, and of the possible paths for navigating through these spaces, is essential for the development of efficient orientation and mobility skills. The work reported here is based on the assumption that the supply of appropriate spatial information through compensatory channels (conceptual and perceptual), may contribute to the blind people's spatial performance. We developed a multi-sensory virtual environment simulating real-life spaces. This virtual environment comprises developer / teacher mode and learning mode.

1. RATIONALE

The ability to navigate space independently, safely and efficiently is a combined product of motor, sensory and cognitive skills. This ability has direct influence in the individuals' quality of life.

Mental mapping of spaces, and of the possible paths for navigating through these spaces, is essential for the development of efficient orientation and mobility skills. Most of the information required for this mental mapping is visual information (Lynch, 1960). Blind people lack this crucial information, thus facing great difficulties (a) in generating efficient mental maps of spaces, and therefore (b) in navigating efficiently within these spaces. A result of this deficit in navigational capability is that many blind people become passive persons, depending on others for continuous aid (Foulke, 1971). More then 30% of the blind do not mobilize independently outdoors (Clark-Carter, Heyes & Howarth, 1986).

The work reported here is based on the assumption that the supply of appropriate spatial information through compensatory sensorial channels, as an alternative to the (impaired) visual channel, may contribute to the mental mapping of spaces and consequently, to blind people's spatial performance.

Research on blind people's mobility in known and unknown spaces (Dodds, Armstrong & Shingledecker, 1981; Golledge, Klatzky & Loomis**,** 1996; Ungar, Blades & Spencer, 1996), indicates that support for the acquisition of spatial mapping and orientation skills should be supplied at two main levels: perceptual and conceptual levels.

At the perceptual level, the deficiency in the visual channel should be compensated with information perceived via other senses. Touch and hearing become powerful information suppliers about known as well as unknown environments. In addition, haptic information appears to be essential for appropriate spatial performance. Haptics is defined in the Webster dictionary (1993), as "of, or relating to the sense of touch". Fritz, Way & Barner (1996) define haptics as " tactile refers to the sense of touch, while the broader haptics encompasses touch as well as kinaesthetic information, or a sense of position, motion and force." Haptic information is commonly supplied by the cane for low-resolution scanning of the immediate surroundings, by palms and fingers for fine recognition of objects' form, textures, and location, and by the legs regarding surface information. The auditory channel supplies complementary information about events, the presence of other people (or machines or animals) in the environment, materials which objects are made of, or estimates of distances within a space (Hill, Rieser, Hill, Halpin & Halpin, 1993).

At the conceptual level, the focus is on appropriate strategies for an efficient mapping of the space and the generation of navigation paths. Research indicates two main scanning strategies used by people: route and map strategies. Route strategies are based in linear (therefore sequential) recognition of spatial features. Map strategies, considered to be more efficient than the former, are holistic in nature, comprising multiple perspectives of the target space (Fletcher, 1980; Kitchin & Jacobson, 1997). Research shows that blind people use mainly route strategies while recognizing and navigating new spaces (Fletcher, 1980).

2. THE PROPOSED STUDY

Advanced computer technology offers new possibilities for supporting visually impaired people's acquisition of orientation and mobility skills, by compensating the deficiencies of the impaired channel.

Research on the implementation of haptic technologies within virtual navigation environments reports on its potential for initial training as well as for support and rehabilitation training with sighted people (Giess, Evers & Meinzer, 1998; Gorman, Lieser, Murray, Haluck & Krummel, 1998), as well as with blind people (Jansson, Fanger, Konig & Billberger, 1998; Colwell, Petrie & Kornbrot, 1998).

In light of these promising results, the main goals of this study are:

(a) The development of a multi-sensory virtual environment enabling blind people to learn about different (real life) spaces which they are required to navigate (e.g., school, work place, public buildings).

(b) The systematic study of blind people's acquisition of spatial navigation skills by means of the virtual environment.

In the following sections a brief description of the learning environment will be presented, as well as preliminary results of the pre-pilot evaluation of it.

3. THE ENVIRONMENT

For the research project reported here, we developed a multi-sensory virtual environment simulating real-life spaces. This virtual environment comprises two modes of operation:

(a) Developer / Teacher mode.

(b) Learning mode.

3.1 Developer / Teacher mode

The core component of the developer mode is the virtual environment editor. This module includes three tools: (a) 3D environment builder; (b) Force feedback output editor; (c) Audio feedback editor.

3.1.1 3D environment builder. By using the 3D-environment editor, the developer can define the environment characteristics. These characteristics are:

- Determine the size and the form of the room.
- Determine the ground texture.
- Selected the objects in the environment (doors, windows, walls, rectangle, cylinder etc.)

3.1.2 Force feedback output editor. By this editor the developer is able to attach Force-Feedback effects (FFE) to all objects in the environment. Examples of FFE's are vibrations produced by ground textures (e.g., stones, parquet, grass etc); force fields surrounding objects; friction sensation.

3.1.3 Audio feedback editor. This editor allows the attachment of appropriate audio-feedback to the objects, for example: "facing a window", "turn right" etc.

Figure 1 shows the environment-building editor screen. The interface allows the developer to determine the different features of the target space, e.g., size, objects, FFE's and audio effects attached to the objects, ground texture.

By using the developer mode, the environment developer can built new navigation environments, accordingly to the need of the users, and to progressive levels of complexity.

3.2 Learning mode

The learning mode includes two interfaces: User interface and Teacher interface.

3.2.1 The user interface. The user interface consists of a 3D virtual environment, which simulates real rooms and objects. The user navigates this environment using the Microsoft Force Feedback Joystick (F.F.J). During this navigation varied interactions occur between the user and the environment components. As a result of this interactions the user get haptic feedback through the F.F.J. This feedback includes sensations such as friction, force fields and vibrations.

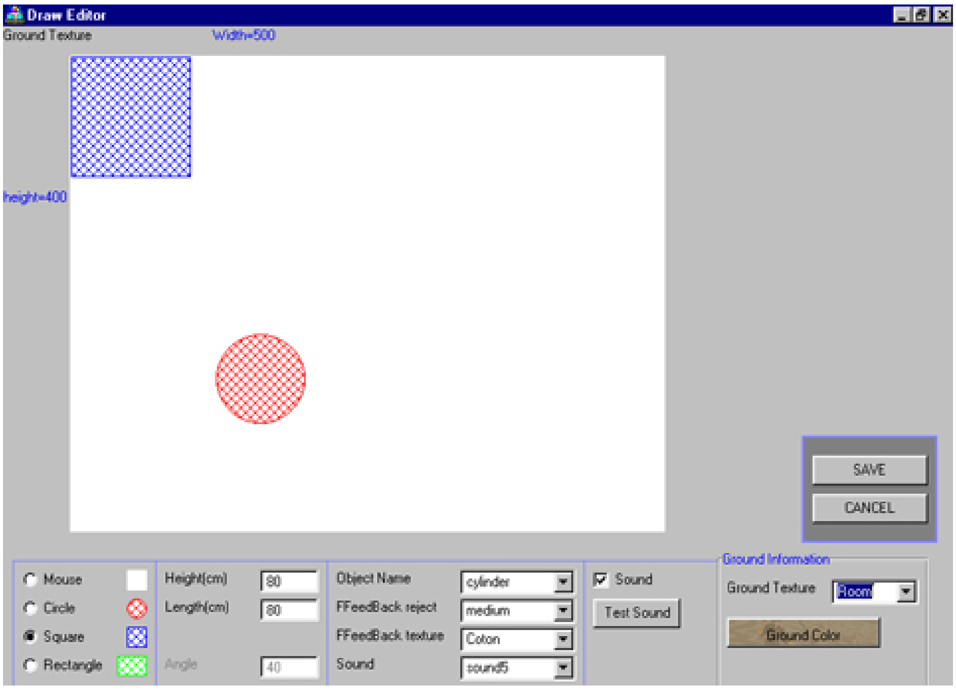

Figure 1. *3D environment builder*

By using the F.F.J the user can get information at two levels:

- Foot level – this mode provides information that is equivalent to the information that the user gets by his feet, as he walks in the real space.
- Hand level – this mode provide information that is parallel to the information that the user gets by his hand in the real space.

In addition the user receives auditory information generated by a "guiding computer agent", contextualized for the particular simulated environment. This audio feedback aims to provide appropriate references whenever the user gets lost in the virtual space. Figure 2 shows the user-interface screen.

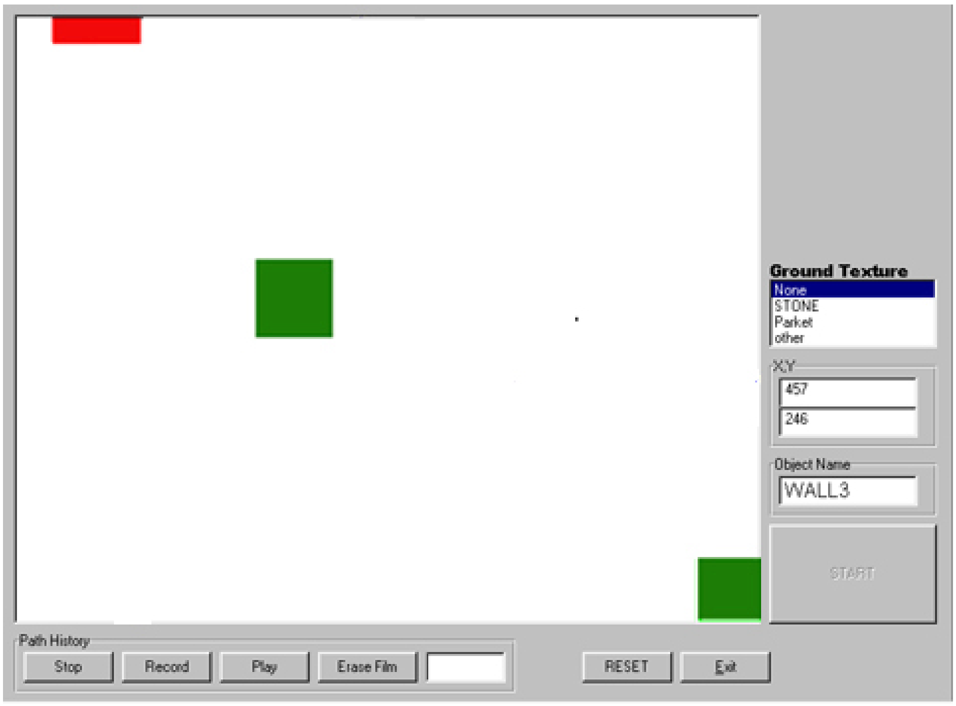

Figure 2. *The user interface*

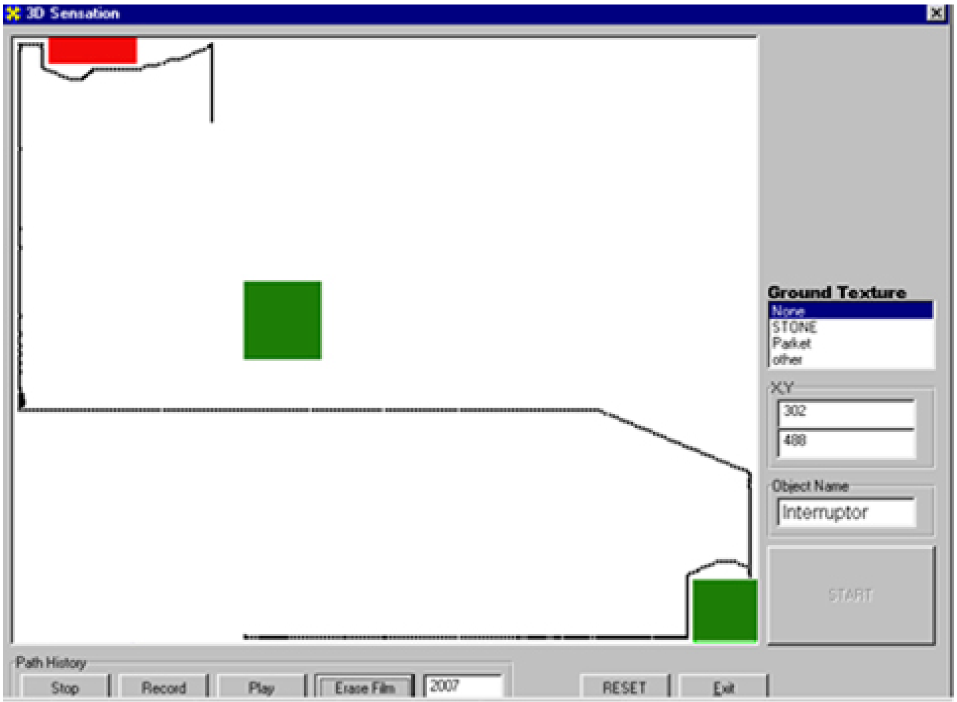

Figure 3. *The teacher interface*

3.2.2 The teacher interface. This interface comprises series of features serving teachers during and after the learning session. Several monitors on the screen present updated information on the user's navigation, e.g., position, objects reached. In addition, other functions allow the teacher to record the user's navigation path and replay it aftermath to analyze and evaluate the user's performance (Figure 3).

4. PRE-PILOT FORMATIVE EVALUATION OF THE FORCE FEEDBACK VIRTUAL ENVIRONMENT

The pre-pilot formative evaluation stage aimed to analyze the user's performance within the environment regarding three main aspects:

(a) User's response to F.F.J, and the type of FFE's that were of high effect on the user.

(b) Users ability to identify the environment's components. Two issues were addressed:

- User identification or recognition of the space and the objects.
- User's difficulties in the identification of the objects' shape and size.

(c) User navigation within the environment. Two issues were addressed:

- Environment characteristics that lead the user to high immersion-feeling.
- User's movement in the environment.

5. METHOD

5.1 Subject

The subject, A., is a forty nine years old, a congenital blind. He is a computer user for more than eleven years. A. using a cane for mobility in outdoor.

5.2 Procedure

The study consisted of two stages: F.F. evaluation stage, and navigation in virtual environment stage.

5.2.1 Force feedback evaluation stage. A series of probes were administered, at which different FFE's were tested by the subject. Data on the subject's reports was collected by direct observation of his performance, and by interview questions. As a result of this stage, a characterization of the potential value of the different effects for the builders of navigational environment was obtained. The F.F. evaluation stage lasted about half an hour.

5.2.2 Navigation in virtual environment stage. At the beginning of the stage the subject received a short explanation about the features of the environment and how to operate the F.F.J. The series of tasks included: (a) free navigation; (b) directed navigation; (c) tasks focussing on emerging difficulties; and (d) task aimed to probe auditory support (human feedback in this preliminary version), referring to direction, turns, and proximity to objects. As a result of this stage, a characterisation of appropriate and required features of the environment and the navigation tools was generated. This stage lasted about forty-five minutes. At the end of this session an open interview was conducted.

5.2.3 Data collection. Three data-collection instruments were used in this study. The first was a log mechanism built-in in the computer system which stored the subject's movements within the environment. In addition the whole session was video recorded. The third data collector instrument was an open interview.

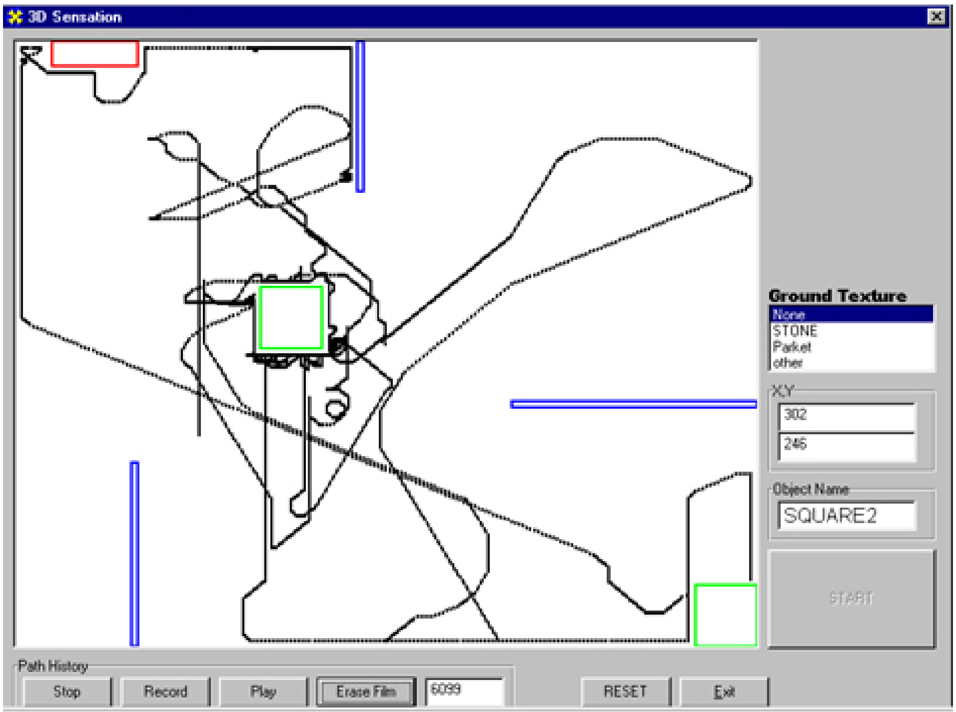

Figure 4. *Subject's navigation in the environment*

6. RESULTS

6.1 Force feedback joystick features

A. Learned to work freely with the force feedback joystick within a short period of time. During the first session A. recommended to define a magnetic force field around the objects and in front of the walls. By this magnetic force field the user can feel an attraction or repulsion whenever he approaches an object or an obstacle. The force feedback characterizations that were effective to the user were high resistance force, bumps vibrations and high frictions.

6.2 Identification of environmental components

A. could identify when he bumped into an object, or arrived to one of the room's corners. The subject could not identify the objects. As a result of the size of the objects and without a magnetic force, the subject was lost in the space.

6.3 Navigation

A. moved within the environment in a rapid response, the rapid walking cause him to get lost in the haptic space. Another reason that made him to lose is way in the space, was the walking at the environment without references.

Figure 4 shows the intricate paths in one navigation task. The paths unveils situations at which the user got trapped in corners, lost referential landmarks in the space, or in contrast, his attempts to grasp the object from all angles.

The pre-pilot probes resulted in the devise of several required improvements:

- Enlargement of the objects.
- Improvement of the resolution of correspondence between the movement and the force feedback.
- Introduction of friction effects for walking along the walls.
- Reduction of allowed navigation velocity in the environment.

At the time of the conference, detailed results from the actual study as well as preliminary conclusions will be presented.

Acknowledgements. The study presented here is partially supported by Grant Microsoft Research Ltd.

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Audio space invaders

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ABSTRACT

Whilst advances are underway in various areas to ease and encourage disabled uptake of new technology, very little emphasis to date has been placed on making the games market accessible to all. The aims of the described work have been twofold. Firstly, to prove that the standard features of a traditional space invader game can be replicated using a 3-D audio (ambisonic) environment. Secondly, through combining audio and visual interfaces with force feedback joystick movement that it is possible to produce a multi-modal game that can be played by both sighted and non-sighted users, thereby enabling them to share the same gaming experience. This paper describes the development and features of the resultant *Audio Space Invaders* game.

1. INTRODUCTION

Digital technologies such as hypermedia, virtual reality, digital video broadcasting, video conferencing, co-operative working and the world wide web have been the subject of intense development over recent years and together may be said to comprise the second information technology revolution. These developments coupled with the continually decreasing costs of the enabling technology have resulted in significant expansion in their use (Harlow and Gadher, 1999). One such area of expansion is that of the home entertainment industry and in particular the video games market, to the extent that computer games are played by almost all children, with many families having a home computer or games console. Most of these games involve the use of computer graphics to navigate a fantasy world. Consequently, whilst the graphical technology of these games has become very advanced and sophisticated, the audio component is often mediocre and only used to add to the realism of a game rather than to assist play it. This can leave blind and partially sighted children feeling excluded and set apart from their peers, as they are unable to participate in these games.

That the inclusion of disabled users in all areas of the new technological revolution is of prime importance is evidenced through the increasing awareness of the requirements and rights of the disabled including those related to inclusive product design (UK Government, 1995; DRC, 2000; W3C, 2000; Disability Now, 1999; FEFC, 1996; FEDA, 1998). With inclusive software design (McCrindle, 1999) in mind we have developed a multimodal games interface for a space invader type of game. In contrast to traditional games development, design of the *Audio Space Invaders* game has been based primarily around a 3-D surround sound environment, with the graphical interface being added later. Force feedback controls further enhance the playing experience of the game.

2. EXISTING WORK

Whilst advances are underway in various areas to ease disabled uptake of new technology, for example use of the World Wide Web (W3C, 2000), very little emphasis to date has been placed on making the games market accessible to all. That such a concept is possible, has been demonstrated by Lumberas and Sánchez (1998) who developed a 3D aural interactive hyperstory specifically aimed at blind children. The project proved that blind children could interact with a computer using an audio interface. It also showed that playing the game helped children build up a model of the fantasy world in which they were playing and resultantly improved their spatial awareness of the real world. Another study into audio interfaces (Mereu and Kazman, 1996) found that by using a 3D audio interface a blind person could locate a point in 3D space as accurately as a sighted person could using a graphical interface, although the time taken by the blind person was significantly longer. It was also found that in a sound only environment visually impaired users were very much more accurate than sighted users. Other ambisonic research (Cooper and Taylor, 1998; Lumberas et al, 1996) also substantiates the effectiveness of 3-D audio environments. Use of force feedback has also been used to guide users through a representation of a GUI (Ramstein et al, 1996) and manipulate the environment. By producing the *Audio Space Invaders* game we have taken the 3-D audio gaming concept a stage further by combining audio and visual interfaces with force feedback joystick movement to produce a game that can be played by both sighted and non-sighted users, thereby enabling them to share the same gaming experience.

3. THE AUDIO SPACE INVADERS GAME

Audio Space Invaders has been implemented in Visual C++ combined with the APIs from Aureal's A3D Software Development Kit (SDK) 2.0 (1999) and Microsoft's DirectX SDK 6.1 (1998, 1999). This has proved to be a very powerful combination allowing the programming of advanced PC gaming features, relatively good portability and excellent driver support.

As the primary aim of this project has been to prove that the standard features of a traditional space invader game can be replicated using an audio environment, incorporation of the following game requirements were deemed to be important:

- The game should be based on a player who his defending himself against may enemy foes.
- The enemy may shoot at a player. This will decrease the player's life, when the player's life reaches zero the player dies and the game ends.
- The player may shoot at the enemy, who also have a life that decreases when they are shot. When the enemy dies, the player's score is increased.
- The game should have a number of different levels each of increasing difficulty.
- The level reached and total score should enable players to rate themselves against each other.

4. GAME SPECIFICATION

The features currently incorporated in a fully working prototype may be briefly summarised as:

4.1 Type of Game

A *shoot 'em up* style of game based on a futuristic space adventure has been developed, as such games are currently very popular with the teenage gaming community. The game incorporates a number of scenario levels, each one based around a player fighting against different types of enemy ships. Each ship type has a certain 'life' that is automatically set to a particular value when the ship is created and decreased every time it is shot. When the 'life' of a ship reaches zero the ship is destroyed. The ships also have different velocities, directions of attack, flight patterns and firing rates. The scenarios are of increasing difficulty and are presented to the player in sequence. For enhanced variability, enjoyment and challenge, each scenario possesses its own unique difficulties and features and to proceed from one level to the next a number of objectives must be met. Each scenario is guided by audio/textual information and played via interaction with a 3-D audio/graphical/tactile interface. Points are obtained by shooting enemy vehicles and by completing the mission objectives. The game can be considered complete when the player has completed the final mission. A total score enables players to rate themselves against each other and against previous plays.

4.2 Adjusting Levels of Difficulty

The scenario levels are initially set with default values, however to adjust the complexity of the game to suit different age groups, disabilities and experience levels, each scenario may be customised using the *Level Editor* supplied with the game (see Figure 1). For example once a player has mastered the inbuilt scenarios, they may be extended by adding extra missiles to the players arsenal.

4.3 Audio Interface

The game is based mainly around a 3-D audio environment. In order to achieve this most effectively, the audio interface was the first part of the program to be designed and implemented. This ensured that other parts of the program were an accurate representation of the audio data. This is in contrast to traditional games development, which tends to concentrate development on the graphical interface, and then tries to associate an audio interface with it. Ideally to give the highest sense of reality to the player, the audio environment consists of a four-speaker surround sound set-up. However the program will also work adequately on sound cards that only support two speakers – in this mode it is especially effective with headphones. For further ease of use instructions are given audibly, audio clues as to what is happening within the game are implemented, and the control system has been made as simple as possible.

4.4 Visual Interface

The *Audio Space Invaders* game does not require a graphical interface for playing purposes. However, a graphical interface has been included for a number of reasons: firstly to provide a more natural mode of interaction for sighted users; secondly to provide a training mechanism to the game for both sighted and non-sighted users; and thirdly to provide a comparative test-bed for research into human computer interaction issues across sighted and non-sighted user communities. During testing it was found that newcomers to the game often experienced initial difficulty in getting their bearings in the audio world. The graphical interface allowed sighted people to work out their relative position to other objects in the game and it is envisaged that via this method a sighted person would help a visually impaired person also learn the game. It may also be of use during game play by partially sighted users. The visual interface may be turned off completely if desired.

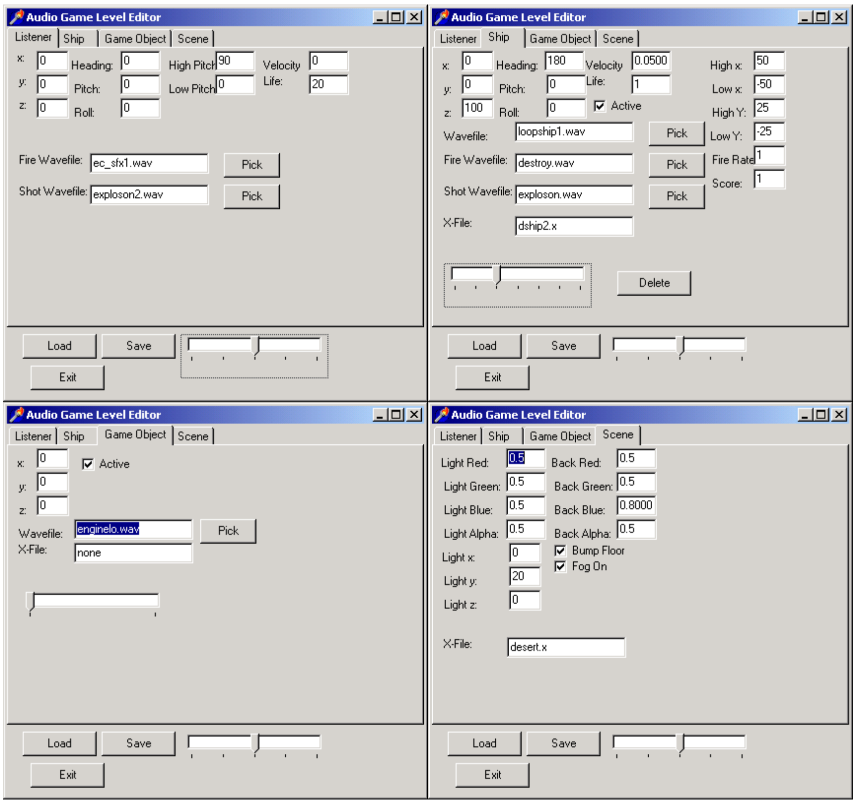

Figure 1. *Level-editor to set degree of difficulty of game and establish new scenarios*

4.5 Interaction

There are two possible control methods for the game – a keyboard or joystick. The keyboard can be used to replicate a number of basic controls: - up, down, left, right and fire. The joystick enables more sophisticated interaction with the game since it allows more than one signal to be processed at once, so for example the user can shoot and move at the same time. Simple keyboard interaction rather than a mouse driven interface has been incorporated as it also assists users with co-ordination impairment since it eliminates the needs for physical dexterity and accuracy that are associated with the use of a mouse. Additionally, blind users who may not feel completely confident with a mouse or joystick may also prefer this method of interaction.

4.6 Force Feedback

The use of an optional force feedback joystick provides extra information and clues to the game situation if the user has one of these devices. Through different movements of the stick the player is able to feel themselves being shot, the shots they are firing etc. and in the future may be used to guide the user through certain events or as a training mechanism. This extra information can be very useful, especially at higher levels of the game when there are several activities going on and hence a variety of different sounds being produced.

4.7 Universality and Affordability

The game has been designed to run on a Windows 95/98 PC of average specification. The recommended minimum specification is a Pentium II with 64mb RAM, Aureal 2.0 compatible sound card (4-speaker) and a force feedback joystick. However acceptable performance is also achieved on a Pentium MMX or equivalent with 32mb RAM and a standard sound card (2-speaker). A player can also turn off features such as the graphics to improve the speed of the game. Although a force feedback joystick is very useful in supplying extra sensory information to a player, it is an expensive device and hence is an optional feature of the game. Additionally, research has also shown that some blind children find a keyboard a more natural method of interaction and hence this is always an available control option.

5. GAME SCENARIO IMPLEMENTATION

There are currently six scenario levels, including an initial training level, each representing the defence of a different planet from increasingly complex formations of enemy ships. Essentially, the player is positioned in a turret on each planet's surface, which is then attacked by the enemy ships. The player has the choice of being reactive and firing at the enemy ships when they are detected audibly or visually within range, or they may be proactive and seek out enemy ships to destroy.

Purposefully, the first scenario level is a training level to teach the users the basic controls and how to play the game. At this level the user is in a turret with four stationary ships placed around them. A ship is placed in front, behind and to either side of the turret. There is also a more powerful enemy ship incorporated into this level to enable the player to recognise the difference between these ships and the normal ships. This level is essential to help players not using the graphical interface learn how to locate ships by listening to where the sounds come from and to differentiate between the different types of ships. Unlike the graphical interface, which is a common way of playing games, the audio interface is quite different to anything else the players will have used before. For example the more powerful ships are given a louder and more high-pitched sound than the normal ships and must be distinguished as they are harder to destroy. Additionally, the turret is given a long life-span in this level. This gives the user ample time to get used to the controls and the ideas of the game. The training level also introduces Molly, a female robotic companion, who instructs the user what to do at each level and what dangers are present at each level of the game. She also offers words of encouragement and gives the user a sense of continuity throughout the game.

Figure 2. *Snapshots of level-2 to show mission instructions, game in play and debriefing*

Figure 2 shows four screenshots taken at various points during Level-2 of the game. The first quadrant shows the start of the scenario with Molly alerting the player to an imminent attack. Information in this mission brief is given about the players position as well as the direction of the incoming ships. Quadrants 2 and 3 show snapshots of the game in progress. Quadrant 2 shows an approaching wave of ships, whilst quadrant 3 shows a ship that has flown over from behind the player. To make the ships sound as though they fly towards and away from the player the Doppler effect is applied to the sound. This effect, which is apparent in normal life, increases the pitch of the sound of the object as it comes towards them and decreases the pitch as the sound moves away. The remaining player life-span and their score are given in the left and right corners of the screen respectively. Such information is also accessible audibly by pressing a keyboard control key and is given automatically should the life-span level become dangerously low. Once the mission has been successfully completed, Molly gives an encouraging debrief to the players as shown in quadrant 4.

Scenario levels-3 to 6 take place on different planets and have increasingly complex flight patterns for the enemy ships, shorter player life-spans, more of the powerful ships etc. However they all purposefully incorporate a similar look-and-feel as shown in Figure 3, which incorporates screen shots taken from level-4. Another ‘twist-in-the-tail’ for pitting blind players against sighted players is that as the levels become progressively more difficult the degree of graphical help for sighted players is lessened by making the planets very dark such that the approach of enemy ships cannot be so readily detected by visual means as shown in Figure 4.

Figure 3. *Consistent look & feel but increasing complexity.* **Figure 4.** *Difficult visual interface.*

The game may be played using audio and visual information in combination or in isolation of each other. The different models can be switched in real-time by pressing a single control key. The game play resulting solely from using the audio interface is shown in Figure5. A series of menus, instruction files and other feedback information screens such as those for game statistics are also incorporated into the game, some of which are shown in Figure 6.

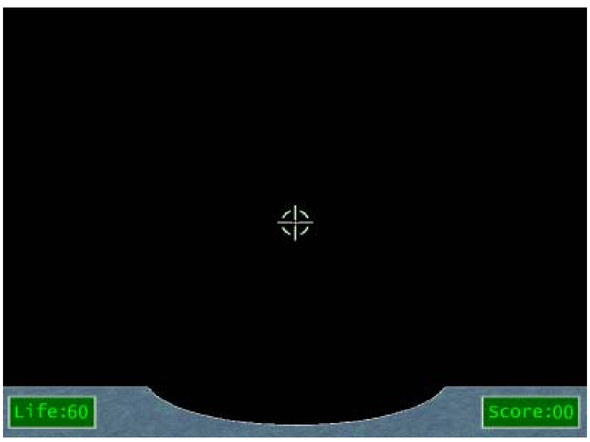

Figure 5. *Game play solely through audio interface.* **Figure 6.** *Introductory and summary screens.*

5. TESTING

Testing has been ongoing throughout development and a number of important observations have been made. In particular users initially found it difficult to distinguish between different sounds and from where they were coming. However, with a little practice they soon became able to locate and shoot the enemy ships. The graphical interface proved a useful training mechanism even for non-sighted users since with the help of a sighted friend they were able to gain an understanding of where the sounds were coming from and what they represented.

Other results were also gleaned about the type of sounds and general game play that were most effective, for example:

- Sounds with a smooth varying pitch were very difficult to locate. It gave the impression that these sounds were moving when they were in fact not.
- Sounds that changed could be located as long as the change was quite harsh. A helicopter's propellers or some other sort of machine were easy to locate whereas a sound like siren was not.
- With more than two sounds the quieter or less distinguishable sounds became masked and were not easy to hear until objects making the louder sounds were destroyed.
- Two or more sounds which were the same or very similar were also difficult to locate, although not impossible.
- Too many sources of sound were found to be detrimental to the game. Originally every time a players score increased or their life-span decreased the information was communicated audibly to the player. This proved to mask out the ship sounds and disadvantage the player. This feature was therefore subsequently changed to the score being read out on demand via a control key and only automatically when a players life was becoming dangerously low.
- There was a very steep initial learning curve particular for sighted people trying the play the game on audio alone, as the task is quite peculiar to a lot of sighted people who rely mainly on images to locate items.
- The game became rapidly more challenging as ships flew with circular motions in addition to straight lines. Further challenges were provided, by having ships flying in both directions over the user and approaching from both sides simultaneously.
- The game is playable using only two speakers although it is obviously better with four speakers. If only two speakers are available it is best to use headphones instead.
- Changing the height of the object has proved very difficult to use with a 4-speaker set-up. The difference in sound is very small and so is currently not used. Further testing is required, possibly within a CAVE environment, to make full use of this feature.
- The positioning of the speakers was found to be essential for maximum efficiency and enjoyment of the game. The speakers should be positioned at approximately head height with the player an equal distance from each speaker.

The initial version of the game has been completed, is comparatively portable across a wide range of PC specifications and is very robust. Preliminary feedback has been exceedingly encouraging. Unfortunately, the more extensive and formal evaluations with blind/visually impaired teenagers originally scheduled for March/April 2000 have had to delayed slightly due to the logistics of term-times and exam timetables. However, these will shortly be underway and all feedback obtained will impact on the continued development of the game.

6. FUTURE WORK

A number of advanced features are also planned for implementation such as incorporation of Artificial Intelligence (AI) techniques to provide added realism to the game and to support help facilities; improved text to speech and speech recognition functions; an increased number of joystick functions; three dimensional graphics; and a networked version of the game to enable several players to interact simultaneously within the same gaming environment. Additionally, exploitation of the new facilities in the recent releases of Aureal's A3D SDK (1999) and Microsoft's DirectX 7.0 (1999) will improve the audio interface and force feedback interfaces respectively.

7. SUMMARY

This paper has introduced the work associated with the creation of an *Audio Space Invaders* game. Substantial progress has been made in a very short space of time and a fully working version of the game produced which successfully incorporates the features described in Section 4 and proves that interactive gaming features can be incorporated within an audio environment. Indeed, such is its success that discussions are underway with a digital company with a view to professional production of the game and its movement into the market place. Further user trails are continuing; a number of other audio games are being developed; and further research into human computer interaction techniques for blind and visually impaired users being conducted.

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Usability and Cognitive Impact of the Interaction with 3D Virtual Interactive Acoustic Environments by Blind Children

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ABSTRACT

It is known that blind children represent spatial environments with cognitive difficulty. This can be decreased if they are exposed to interactive experiences with acoustic stimuli delivered through spatialized sound software. A few studies have approached this issue by using interactive applications that integrate virtual reality and cognitive tasks to enhance spatial orientation skills. The aim of this research was to implement a field study to detect and analyze cognitive and usability issues involved in the use of an aural environment and the issues of representing navigable structures with only spatial sound. This experimental study has arisen from a challenging pilot research project to a full fledged field-testing research with eleven children during six months in a Chilean school for blind children. The research was implemented by using a kit of cognitive representation tasks, which includes exposure to the 3D acoustic environment, corporal exercises, and experiences with concrete representation materials such as sand, clay, storyfoam, and Lego bricks. The cognitive kit also included activities to represent the perceived environment, the organization of the space, and problem solving related to the interactions with the software. The usability testing of the environment was an explicit issue in the research by using both qualitative and quantitative methods including interviews, survey methods, logging actual use, still pictures, and video tape recording session analysis. The idea was to motivate and engage blind children to explore and interact with virtual entities in challenge-action software and to construct invisibly cognitive spatial mental representations.

The results of the study revealed that blind children can achieve the construction of mental structures rendered with only 3D sound and that spatial imagery is not purely visual by nature, but can be constructed and transferred through spatialized sound. Our hypothesis was fully confirmed revealing that each blind child passes four clear stages in their interaction with the sound environment and performing cognitive tasks: entry, exploration, adaptation, and appropriation. We also conclude that the child possesses both unique skills and pace referred to mental and spatial development, impacting directly on the quality of the topological features obtained in comparison to the ideal reference spatial structure embedded in the software.

1. INTRODUCTION

Integrating Virtual Reality (VR) to medicine appear to be an attractive combination that has been received media attention interest recently. The main stream comes from the fact that VR or more accurately Virtual Environments (VE) provide novel methods of visualizing and interacting with complex data sets. The first applications of VE are related to education and training, such as teaching of anatomy content [Weghorst 92], minimally invasive surgery training, diagnosis -visualization and navigation of medical image data sets-, rehabilitation [Whalley 93] -control of fears and phobias-, prosthetic use of advanced computer interfaces - i.e. glove talker system allows a person with speech difficulties to communicate by means of hand gestures while wearing a DataGlove virtual hand controller [Greenleaf 92]-, numerical cadavers, surgical simulators, visualization of data sets, and telesurgery.

Recently, VR and VE are used to enhance or ameliorate the cognitive and navigation problems of blind users. If we study how this technology assist blind users we can classify it according to the following type of applications:

- Web browsers: Web speech browsers designed for users that wish to access the Internet in a non-visual or combined auditory and visual manner such as BrookesTalk [Zajicek 98], WebSpeak [Hakkinen 96], MarcoPolo [Owen 97], AHA (audio HTML access) [James 98], DAHNI - Demonstrator of the ACESSS Hypermedia Non Visual Interface- [Morley 98]. All these approaches explore the fundamental issues of auditory navigation through hypermedia information.
- Universal access to computer systems: the main idea here is to provide generic access to the legacy of resources of standard computer systems. For example, Emacspeak [Raman 96] was designed to provide impaired users with productive access to the wealth network computing resources available on UNIX platforms. Other projects are Mercator [Mynatt 92] to provide generic access to the X-Windows platform without visual cues, and the european GUIB (Graphical User Interface for the Blind) to enable access to the MS Windows operating system.
- Presentation of information from graphical nature: A promising area for sound issues is the sensory substitution of information for visual nature by audio information for visually impaired users. Schemes for auditory rendering of maps and diagrams embedded in are being developed. Some authors have developed means for scanning arbitrary visual images and presenting them in sound. Also, there has been increasing interest in augmenting haptic displays with sound for purposes of presenting graphical information.
- Interactive 3D environments: The Spatial Auditory Environment in a Ring Topology [Savidis 96] aims to provide a multimedia toolkit for non-visual interaction to provide a 3D auditory navigation environment. This system will enable blind users to review a hierarchical organization of auditory interaction objects by using direct manipulation techniques through 3D-pointing hand gestures and speech recognition input.

The use of VR as interactive technology to explore users representing and interpreting symbolic objects and simulated environments in their minds has received little attention in the literature and empirical arena. It is known that blind children represent spatial environments with cognitive difficulty. This can be decreased if they are exposed to interactive experiences with acoustic stimuli delivered through spatialized sound software. A few studies have approached this issue by using interactive applications that integrate virtual reality and cognitive tasks to enhance spatial orientation skills. In this study, by using 3D acoustic interactive virtual environments fully described elsewhere [Lumbreras & Sánchez, 1998, 1999a], we attempt to assess cognitive and usability issues involved in the rendering of spatial structures in the mind of blind children through acoustic navigable virtual environments. The idea behind this is to motivate and engage blind children to explore and interact with virtual entities in challenge-action software, and to construct invisibly cognitive spatial mental representations.

The aim of this research was to implement a study to detect and analyze cognitive and usability issues involved in the use of an aural environment and the characteristics of representing navigable structures through spatial sound. This study has arisen from a challenging pilot research project [Lumbreras & Sánchez, 1998, 1999a] to a full fledged contextualized and field-testing research with eleven blind children during six months in a Chilean blind school. In this work we also describe the cognitive effects on children when interacting with this software environment in terms of the development of cognitive spatial representations as a result of interacting with a 3D acoustic environment [Lumbreras & Sánchez 1999b; Sánchez & Lumbreras 1999; Sánchez 2000 a, 2000b, 2000c].

2. METHODOLOGY

The research was implemented in a Chilean blind school. We extract an intentional sample of eleven first and second grade children coming from social and deprived suburbs. The size of the sample was established by considering some restrictions such as: school time slots and space available, structural and topological conditions of the school, PC availability, and the number of special education teachers and assistants we work with. Some of these children live in their homes and others live in the school in an internship system that allows them to go home during the weekends. The ages of the children spanned from seven to twelve years old. There were children with total blindness and some with residual vision. In addition, some of them have some degree of cognitive and learning disabilities. Diagnostic tests were applied to develop a profile of each child that included ages, type of blindness, affective background (maturity, tolerance to frustrations, irritability, emotional capacity, self-esteem), and cognitive (Wechsler verbal scale) and psychomotor level.

Besides to the 3D virtual environment designed for a pilot experience [Lumbreras & Sánchez, 1998, 1999a], we built a *kit of cognitive representation tasks* (see Fig.1). They include different levels of exposure to the interaction with the 3D acoustic environment, experiences with corporal movements in the schoolyard, model building in a sand table and with other concrete materials such as clay, styrofoam, Lego bricks, plastic images, wood cubes, metal pins, small balls, and sand paper. Six tasks were carefully planned with objectives, time, and number of pedagogical sessions and procedures. The kit also includes learning activities to represent the perceived environment, the organization of the space, and problem solving related to the interactions with the software. The usability testing of the environment was an explicit issue in the research by using both qualitative and quantitative research methods including interviews, survey methods, logging actual use, still pictures and video tape recording session analysis.

Figure 1. *Sequence of activities from interacting with the 3D virtual environment to model building.*

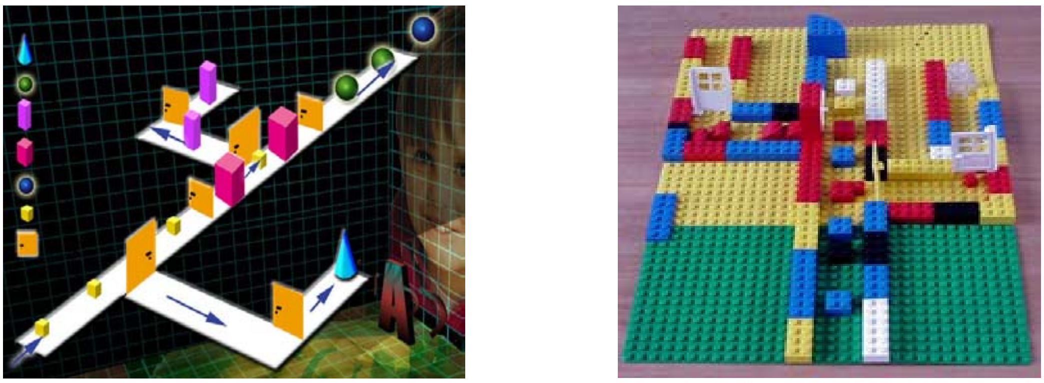


Figure 2. *Left, spatial map embedded in the 3D virtual environment to be represented by the blind children. Right, final map built by a blind girl.*

3. RESULTS

3.1. Cognitive achievement

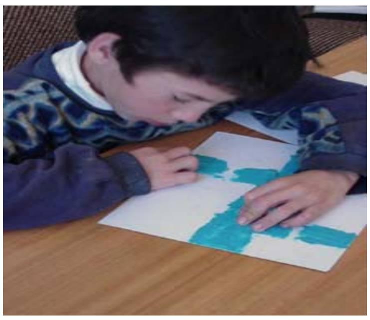
As a result of the empirical research we have arrived to the description of four clear stages in the interaction of the child with the 3D sound environment and the mental mapping of the spatial structure. The achievement of the stages was manifested by different levels of fidelity in the model design in comparison with the ideal software embedded structure (see Fig 2). The stages are:

- Entry
- Exploration
- Adaptation
- Appropriation

The *entry* was the initial interaction with the 3D virtual environment. The child learns different spatial concepts that are prerequisite to make an adequate organization of the environment. The child develops self-esteem and autonomy when interacting with the environment. The child starts representing the space mentally through the story of the software. The representations are very incomplete and unclear. The main characteristic of this level is that the child interacts with the software and is highly motivated to do this. The child's level of control of the software is low.

The *exploration* was represented by a general representation of the structure embedded in the 3D sound environment made through corporal movement in the schoolyard (see Fig 3, right). The main attention is centered on the exploration of the software. The child reaches the representation of the main corridor but no details and secondary corridors are represented with concrete materials (see Fig 3, left). The child develops spatial notions through virtually moving through a virtual space oriented by acoustic information. The child can represent the mental images of the virtual story space with concrete materials exclusively based on acoustic information, showing coherence between concrete representations and story virtual space navigated through acoustic means. The interaction with the story of the software gives confidence and autonomy to the blind child. The child's level of control of the software is medium.

Figure 3. *Left, concrete representations reach only the idea of a main corridor. Right, corporal movement made by a blind girl to make a general representation of the map embedded in the 3D sound environment.*



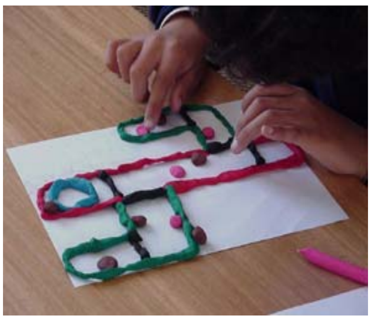


Figure 4. *Representations with clay when the child is in the adaptation stage (left) and the appropriation stage (right).*

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The *adaptation* was attained by the representation of all corridors. The child understands that the structure embedded in the 3D sound environment is composed of one main corridor and two secondary corridors that are perpendicular to the main one. The child solves the conflict created by the entrance of the secondary corridors by understanding that this involves a change in the orientation of his/her movements. Even though the corridors are mapped the representation is incomplete (see Fig 4, left). The child's level of control of the software is high. The child makes more complex representations of the virtual environment.

A complete understanding and mapping of structure embedded in the 3D sound environment was reached in the *appropriation* stage. The main characteristic is the child's mastery of the environment The child understands the story of the software and use it effortlessly as an interesting tool. The child maps a main corridor with the possibility to move throughout divergent corridors passing by doors that make changes in the orientation of the movement, evidencing a full comprehension of the story virtual space (see Fig 4, right). The child's level of control of the software is complete. As a result, the child constructs a complete mental image of the 3D environment, which are represented concretely with high fidelity, quality and complexity in terms of the structure of the navigated story, elements used, and entities involved.

3.2. Levels of cognitive achievement

Not all children attained the level of appropriation. This was explained by the fact that there were other uncontrolled (but known) variables playing a significant role in the expression of our dependent variable, level of mental spatial representation. Actually, the sample was diverse. Some children have total blindness and some have residual vision. Some could use their residual vision to interact with the visual interface and localize visually the keystrokes of the keyboard. Others have just color, light/shadow vision with almost no effect in the interaction. Two children have mental disorders and spasm hemiplegy.

We identify three levels of achievements in our research: high, medium, and incomplete. *High achievement* was reached by students with residual vision and totally blind. They represent the virtual space with high fidelity, comprehend completely the spatial structure of the software and move easily through the software making flexible changes in the orientation of the movements. They make correct design mock-ups with corridors, door distribution in the space, organizing elements and entities, and showing correctly the entry and end points of the story. There is a high coherence between the concrete representations and the virtual space navigated through sound. The narratives given by the children when explaining their work include important details such as different modes to end the story depending on the corridor they enter.

Students with residual vision attained the level of *medium achievement*. They comprehend the existence of lateral and main corridors but cannot orient him/herself when passing through lateral doors. They are unable to make a complete second change in the orientation when moving through the virtual space. They do it with only one lateral corridor. The cognitive mapping of the story complexity is incomplete.

Students with cognitive and learning disabilities reached the level of *uncompleted achievement*. Because of their limited cognitive development their performance stops when we added complexity: more corridors, more elements, more entities, and more orientation movements. The children cannot related corridors, they perceived them as entirely separated from the main corridor.

3.3. Comparative results between sighted and blind children

A group of sighted children of the same ages and characteristics of our blind children sample coming from a regular primary school was exposed to the interaction with the 3D environment. Our goal was to check how they behave and represent an audio-based virtual environment and compare their representations with the ones made by blind children.

As a result, on the one hand, the sighted child (left side of figure 5) only represents the main corridor and some entities in the surrounding space (sand). The child represents the navigated environment partially, including some elements that do not exist in the software (clay). The representation is unclear, including different elements of the environment (Lego).

On the other hand, the blind child represents completely the main and additional corridors (sand). The child maps the main corridor with high fidelity, but additional corridors are incompletely represented (clay). The child represents an exact map of the environment with the main and additional corridors displayed as in the original model of the software (Lego).

Figure 5. *Comparative representations with sand, clay, and Lego between sighted (right) and blind (left) children interacting with the 3D sound virtual environment.*

4. DISCUSSION

This research revealed that it is possible to achieve the construction of mental structures rendered with 3D sound in conjunction with a set of cognitive tasks. The 3D environment by itself does not make any difference in the development of spatial structures in blind children. Cognitive tasks with pedagogical implementations are critical to get good results.

Spatial imagery can be transferred through spatialized sound delivered by 3D-software environments and appropriate methodology. However, not all the children reached the same cognitive stage in their spatial representation. The highest level we defined, the appropriation level, can be attained by most children but they need different rhythm, pace and emphasis. When the blind child has another deficit besides to his/her blindness the development of spatial structures is more complicated and requires a dedicated coaching with more time and slow pace. We believe that all blind children can reach the stage of appropriation if there is a careful design that maps the needs, background and requirements case by case.

As a result of exposing blind children to the aural environment, we believe that each child possesses both unique skills and pace referred to mental and spatial development, impacting directly on the quality of the topological features obtained in comparison to the ideal reference spatial structure embedded in the software.

An interesting testing came out when we compared sighted and blind children. The picture shows us that sighted children (and probably adults)do not rely on sound to construct their spatial structures as blind children could do. The learning through sound is very poor in sighted children. 3D environments such as the one used in this study can be used to enrich the cognitive experience of sighted children heavily based on images. Perhaps there is an entire new story in terms of using sound not just for emotions as we see mostly today, but rather to help to construct richer mental experiences.

Finally, we have confirmed the results obtained in a pilot testing. This research design was deeper, longer, more systematic, cognitive focused, and full of diverse experiences with concrete materials. We also arrive to a clearer picture of the role of 3D sound software in the construction of spatial structures. With a set of clear concepts we are moving to a direction of making more powerful and flexible the maps embedded in the software. Right now we are building a set of 3D sound editors for special education teachers and parents. We also are studying another effects of 3D sound environments such their impact on the construction of temporal cognitive structures and the development of perspectives in the mind of blind children.

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The quest for auditory direct manipulation: the sonified Towers of Hanoi

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ABSTRACT

This paper presents a study of an auditory version of the game Towers of Hanoi. The goal of this study was to investigate the nature of continuos presentation and what this could mean when implementing auditory direct manipulation. We also wanted to find out if it was possible to make an auditory interface that met the requirements of a direct manipulation interface. The results showed that it was indeed possible to implement auditory direct manipulation, but using Towers of Hanoi as the underlying model restricted the possibilities of scaling the auditory space. The results also showed that having a limited set of objects, the nature of continuos presentation was not as important as how to interact with the auditory space.

1. INTRODUCTION

The use of computers today is very dependent on the user's sight. The information is presented visually and sound is primarily used as very primitive queues for important visual information. This may not cause so much problems today for a blind computer user using a screen reader, given that all non-textual information has some sort of alternative description linked to it (which of course is not true, but for the sake of argument we will assume that this is so). But what about the other benefits that a graphical user interface gives a sighted user?

Representing the information using speech synthesis or Braille is a very linear way of presentation and has more in common with the old text based interfaces such as MS-DOS than it has with modern graphical user interfaces such as Windows or MacOS. And what about the next generation interfaces where the standard desktop environment is replaced by something completely different? Why should blind computer users still have to struggle with text based interaction?

1.1 Direct manipulation

Direct manipulation is a fundamental concept within HCI (human-computer interaction) and is based on the following properties:

- *Continuos representation of the object of interest.*
- *Physical actions or labelled button presses instead of complex syntax.*
- *Rapid incremental reversible operations whose impact on the object of interest is immediately visible.* (Schneiderman cited in Hutchins, Hollan, & Norman, 1985)

This means that you for example when moving a file instead of typing the command on your keyboard or choosing from a list of actions, you simply point your mouse at the file you want to move, grab it by pressing down the mouse button, drag it to the place you want it to be and drop it by releasing the button. Another important feature of direct manipulation is that it relies on recognition rather than recall, for example the use of menus helps the user to remember the name instead of forcing the user to memorise the exact name and the exact syntax of the command of interest.

Direct manipulation has been very influential in today's graphical user interfaces and will influence the way we interact with computers for a long time.

1.2 Screen readers

In present screen readers for blind computer users, direct manipulation as well as a number of other important features of the graphical user interface are missing. Mynatt has summarised five goals for screen reader interface design (1997):

- Access to functionality. The screen reader should at least give the user access to the same functions as are presented in the graphical user interface. In a graphical user interface, most functions are represented as pull-down menus. The screen reader should give the blind computer user access to this functionality.
- Iconic representation of interface objects. The screen reader has to be able to recognise and present the same information as is communicated by the visual appearance of the interface objects such as the picture, size and colour. For example, the picture of a trash can on an icon in MacOS symbolises that the icon represents the trash can and that it is a suitable place to throw things one want to get rid of. The shape of the icon tells the user whether the trash can is empty or has things in it.
- Spatial arrangement. The spatial arrangement of the graphical objects also conveys information that helps the user in structuring and working with many tasks at once. The screen reader should offer this functionality.
- Constant or persistent presentation. Visual information is not time dependent in the same way as audio is. The visual information exists in physical space and can be obtained and reviewed at any time; this is not the case for audio information. The screen reader should support this kind of temporal independence.
- Direct manipulation. The screen reader should give the user the same powerful means of interaction as direct manipulation does.

If auditory direct manipulation is to be implemented, all of these items have to be solved.

Auditory direct manipulation is a rather uncharted territory both in research and development, given that we talk about real direct manipulation and not just interacting directly or almost directly with interface objects. In the GUIB project for example (GUIB Consortium, 1995) the work has been concerned with giving the blind computer user a more direct way of interacting with interface objects, but it has not dealt with direct manipulation itself. Other work has been done on complex auditory interfaces (see for example Gaver, Smith, & O'Shea, 1991), but most of these has been monitoring tasks were the focus has been on the display of information rather than the interaction with it (Saue, 2000).

2. GENERAL GOALS

The two questions we want to address are

- Is auditory direct manipulation at all possible?
- Is auditory direct manipulation at all interesting or do we have to seek other paradigms for interaction with an auditory interface?

In order to answer the above questions we have implemented three different audio-only, non-visual, versions of the game "Towers of Hanoi" (see for example Ball, 1939). We also performed two user studies on these three versions. The goal of the studies was to investigate the first principle of direct manipulation, continuos presentation, and what this could mean in an auditory interface.

The three different levels of continuos presentation under study are *parallel*, *serial*, and *overlapping* presentation mode. The first extreme case is when all sounds keep repeating simultaneously, the parallel presentation. The other extreme is when there is no overlap at all and the sounds are played in sequence, the serial presentation. Finally, we implemented a mixture of theses two with a slight overlap, the overlapping presentation (see Sonification model for a more detailed description of these).

3. TOWERS OF HANOI

The game "Towers of Hanoi" consists of three towers where a number of differently sized discs are placed. Initially all discs are placed on the leftmost tower with the discs placed in order with respect to size with the smallest disc on top. The goal is to move all the discs to the rightmost tower. You are only allowed to move one disc at a time and this disc has to be on top of a tower. You can move this disc to any of the three towers just as long as you don't move a larger disc in top of a smaller one. This game can be played with as many discs as you want without having to use more than three towers. The number of moves to complete the game increases rapidly when adding discs, the number of moves it takes to solve the game for *n* discs is 2^n-1. This means that three discs take 7 moves, eight discs takes 255 moves and sixty-four discs takes $1.8 \cdot 10^{19}$ moves to complete.

We chose this game for three reasons; (1) we wanted to have a game that could be fun and challenging to solve, not a typical experimental task, (2) the rules of the game are fairly easy to learn and the strategy is straightforward and doesn't change when increasing the number of discs, just the number of steps in the solution path, and (3) it's easy to show the subjects a wooden model of the game in order for them to learn how to solve the game (this applies both for blind and sighted subjects).

4. SONIFICATION MODEL

In the experiment we studied two factors, *game complexity* and *presentation mode*. Game complexity varied at two levels, referred to as *3disc* and *4disc*. Presentation mode varied at three levels referred to as *serial*, *overlapping* and *parallel*. See the next section for a discussion of the experimental design.

In the 3disc condition, three discs were moved between three towers. In the 4disc condition, four discs were moved between three towers. We also want to represent the height of any given disc on a tower. This requires the representation of up to four discs, three horizontal locations and up to four vertical locations. To accomplish this in sound, each of the discs is identified through associating it with a sound of a specific quality, and the positions of the discs are given through spatialising the sounds in stereo, varying their amplitude envelopes and varying their length. We discuss these features of *disc identity* and *disc location* below.

4.1 Disc identity

Timbre and pitch variations are used to individuate the discs. The larger the disc, the lower the pitch. Let us call the largest disc 1, and the smallest disc 4. The sounds are mistuned with respect to each other and only rarely have partials of the same frequencies, which helps to maximise their discriminability. The fundamental frequencies of the sounds are: 118 Hz (disc 1), 181 Hz (disc 2), 336 Hz (disc 3) and 456 Hz (disc 4). (In the 3disc condition, only discs 1, 2 and 3 were used.)

Disc 1 has a sparser harmonic spectrum than disc 2 and, similarly, disc 3 has a sparser spectrum than disc 4. Furthermore, discs 1 and 2 have fewer high frequency partials than discs 3 and 4. Any combination of discs will differ from any other combination in terms of both pitch and timbre, and do so in a unique way. There is a large gap in frequency between disc 2 and 3 so as to stop the sounds from fusing together when three or more are heard from the same location in the stereo image (cf. Bregman, 1990).

The distinctions between the discs involve some redundancy or overcoding, being conveyed through simultaneous variations in more than one auditory dimension. This is necessary when only one single auditory dimension is difficult to perceive in a complex auditory space (Kramer, 1994).

4.2 Disc location

To represent the tower a disc is located on, stereo panning is varied, left, centre and right stereo locations are used. The spatial discriminability of the sounds is further enhanced by varying their amplitude envelope. Individual discs are presented by pulsing their sounds. The character of the envelope of each pulse is varied to indicate which tower a disc is located on. If a disc is placed on the left or right tower, the percentage ratio between attack and decay is 0:100. If a disc is placed on the middle tower, the same ratio between attack and decay is 50:50.

As with disc identity, the spatial location of the discs is represented redundantly by simultaneously varying panning and amplitude envelopes.

A disc's vertical position is represented by the length of the pulse, the higher the disc is placed the shorter the sound. For example, if two discs are placed on the same tower, the one in the lowest position has a longer pulse length than the one on top. The pulse lengths are 900, 600, 333, and 238 ms.

4.3 Presentation modes

To represent the overall configuration of the Towers of Hanoi at any given moment, three (in 3disc) and four (in 4disc) inter-related series of pulses are to be heard. The relative timings of these series, and the inter-pulse intervals within them, have been designed in three different ways.

- The serial condition. The pulses for the discs are repeated in numerical order without any delay or overlap. As the pulses vary in length to represent the height on the tower, the inter-pulse interval in this condition will vary depending on the location of the discs.
- The overlapping condition. The inter-pulse onset interval is set to a constant value of 300 ms. Accordingly, a pulse associated with a disc will overlap with that of another if the following disc is not placed on top of three others (it's pulse length is smaller than the inter-pulse interval). Discs 1, 2 and 3 (and then 4 in 4disc) are repeatedly pulsed in order.
- The parallel condition. The discs are pulsed continually and simultaneously. For each disc, the onset of a new pulse occurs immediately after the release of the previous one.

4.4 Mouse location

We used the mouse as the input device. In order for the user to track the mouse cursor, the amplitude of the discs on the tower where the cursor is located on is increased while the other discs amplitudes are decreased (the difference is 1:3). Just using this amplitude focus can cause problems when all discs are located to either right or left, since there are no sounds to indicate the difference between middle and the opposite side. To solve this problem we are also using transition tones that will sound when moving the cursor from one tower to another. If moving to left or right from the middle, a short high tone (600 Hz for 500 ms) will sound from left or right. If moving from left or right to the middle, a short lower tone (400 Hz for 500 ms) will sound from both left and right.

5. THE STUDY

5.1 Hypotheses

- It is possible to design an auditory interface that meets the requirements of direct manipulation as defined above.
- The overlapping presentation mode will be the version that most subjects will both prefer and get the best results from using. This will be further emphasised when increasing the complexity (using four instead of three discs).

When presenting the sounds using the parallel presentation mode, it will be easy to get a general overview of all objects, but the separation could be quite hard when having many objects. Furthermore, continuos sounds, or continuos presentation of sounds, could be harder to separate (cf. Gaver, Smith, & O'Shea, 1991) and masking would be more likely.

When using the serial presentation mode there is no problem of separation of the objects since there is no sounds ever overlapping. On the other hand, the general overview is harder since the user has to wait until all sounds has been played to get an overview. If the auditory interface is supposed to support direct manipulation and the number of objects is large, this is could hardly be called continuos presentation in that case.

Since both of these presentation modes both have drawbacks and advantages in comparison to one another, a combination of these seems to be the most appropriate, namely the overlapping presentation mode.

5.2 Experimental design

The experiment is designed to be a two factor within subject design. The first factor is presentation mode and is varied at three levels, serial, overlapping and parallel. The second factor is game complexity and is varied at two levels, three and four discs. Each subject played the game once for every combination of the two factors, which means that every subject, played the game six times. The sequence of the combinations was counterbalanced using a Latin square.

During the experiment two quantitative measurements were made, number of errors (or rather the number of extra steps in the solution path compared with the optimal path), and time to complete. After the session the subject answered questions about which presentation mode they preferred and which they thought they performed best with.

The quantitative data had to be analysed using nonparametric statistical methods, since the measurements neither could be classified as ratio or interval, but rather as ordinal measurements. Additionally, these methods are very insensitive to extreme values, something that is important in an experiment were one might expect a learning effect that will vary between different subjects. The three level factor (presentation mode) was analysed using the Friedman two-way analysis of variance by ranks. The two level factor (game complexity) was analysed using the Wilcoxon signed ranks test.

The experimental set-up was very simple. The subject used a pair of earphones and a regular computer mouse, the computer screen was turned away from the subject and was used exclusively by the session leader to monitor what the subject was doing.

A session started with the subject being informed about what was going to happen during the experiment and the purpose of the study. After this, the subject learnt to play the game using a wooden model of the game. This continued until the subject knew how to solve for both three and four discs without making any errors. By doing this we are trying to even out differences in prior knowledge of the game and get all subjects to have a useful and similar model in mind when solving the auditory version of the game. After the subject has been accustomed to the game, the wooden game is taken away. Now the sonification model is presented. All aspects are described and demonstrated to the subject and the subject is allowed to ask questions and hear every detail as many times as he or she wants. The subject is also informed that this is the last chance of asking any questions about the game or the sonification model. When the subject thinks that he or she knows the sonification model the experiment starts. After all combinations of the game has been completed, the session ends with the subject answering a number of questions about preferences and perceived performance

5.3 The first study

The results of the first study was more concerned with the sonification model and the experimental design than on the question of continuos presentation (Winberg & Hellström, 2000). Of the twelve subjects, three could not complete all or some of the conditions. The two things that caused these dropouts, and caused problems for all subjects for that matter, were the mouse interaction and the instructions.

The sonification model during this first study differed from the one described above in how the mouse interaction was designed. The amplitude ratio was smaller (1:2) and there were no transition tones. Most subjects had big problems tracking the mouse cursor when there were no transition tones. Many subjects found it very hard to find the middle tower, flipping the cursor from left to right without ever finding the middle. This had a very randomised effect on their results, making the collected data very unreliable.

The instructions that the subjects received were also something that caused problems. Many subjects simply did not understand the sonification model at all, invalidating the basic assumption that all subjects would have a model of the game and an understanding of the sonification model before the experiment started.

Despite all these problems encountered during this first study, as stated above nine out of the twelve subjects actually understood and achieved well in the experiment. Due to these problems, we had no interesting or valid data to do any statistical calculations on. But the qualitative results pointed towards a strong preference for the overlapping version and the subjects also thought that they performed better using this presentation mode, even though this was nothing that could be deduced from the measured data.

5.4 The second study

When planning the second study, we introduced transition tones and increased the amplitude difference to enhance the mouse interaction (see Mouse location above). We also changed the instructions and described the sonification model more thoroughly to the subjects. By doing these two adjustments, we hoped that that the problems encountered in the first study would be eliminated. The rest of the set-up and experimental design remained the same in the second study.

The outcome of the second study was very encouraging. None of the problems with the mouse interaction from the first study appeared, none of the subjects had any problems tracking the mouse cursor or finding the middle tower.

Again, as suspected, the subjects preferred the overlapping version, but when it came to the statistical analysis, the results were very surprising. The hypothesis that the overlapping version would be better could not be supported by the analysis. The only significant results we got were that when using the overlapping presentation mode it took more time to complete with four than three discs (Wilcoxon z_{time}=-2.275, p<0.05), a result that is not interesting at all since the number of moves is greater. The differences in number of errors between presentation modes were also significant, but only when using three discs (Friedman χ^2_{errors}=7.032, p<0.05), not when using four discs (Friedman χ^2_{errors} =0.391, p>0.05, χ^2_{time} =1,167, p>0.05), something that the hypothesis suggested. We did not find any significant difference between the three presentation modes in general either (not taking the number of discs into account) (Friedman χ^2_{errors} =2.909, p>0.05, χ^2_{time} =3,583, p>0.05).

5.5 Subjects

We used twelve subjects in each study. Of these, just one was blind in the first study and none during the second. The reason for not using more blind people, who indeed are the focus of this work, is that in this early stage of this work we wanted to fine tune the experiment and the sonification model so that we wouldn't "waste" the blind subjects by letting them participate in an experiment that might not give any interesting or valid results. Additionally, in this early stage we are interested in such a low level questions that the difference in experience of auditory interfaces between blind and sighted subjects is of minor importance. The continuation of this work will definitely involve blind users in defining, designing and evaluating the auditory direct manipulation interfaces.

6. DISCUSSION

The first question one might ask is whether a sonification of the game Towers of Hanoi is complex in a relevant and interesting way and if it really helps answering the hypotheses. The sonification and the study of Towers of Hanoi as an auditory direct manipulation interface should not be seen in isolation. As will be pointed out below, this is just the first of a number of studies on auditory direct manipulation. However, this study has given us important pointers were to go from here.

The second question is why we have chosen the sounds that we have, why haven't we chosen real world sounds like auditory icons (Gaver, 1994) and used natural mappings. The reason for choosing abstract sounds is primarily the scalability (cf. earcons in Blattner, Sumikawa, Greenberg, 1989) of the model. Adding to this is the fact that the concept of metaphorical or real world sounds is hard when displaying abstract concepts. There is even research that reports that there are many acoustical mappings of auditory variables that doesn't necessarily have to be perceived the same by all listeners, even though they would be considered intuitive or natural (Walker, Kramer, & Lane, 2000).

The sonification of "Towers of Hanoi" presented in this paper meet the requirements of a direct manipulation interface.

- The objects are presented in a continuos manner (or rather in three different ways that all could be considered continuos enough). This means that the user rather than scanning the whole interface for objects with the mouse risking missing some of them can hear all objects all the time without actually "looking" for them.
- We have physical actions instead of complex syntax. Instead of choosing the appropriate action from a menu or typing it on the keyboard, the user picks up, moves and drops the object just like a graphical user interface.
- All actions are rapid, incremental and reversible with immediate feedback. There are no detours when performing an action, the only way of moving a disc is using the shortest path between the start and the goal. If the user decides that a move is wrong, it is as easy to move it back as it was moving it there.

The hypothesis that the overlapping presentation mode would be better could not be supported by this study, even though this is what we expected. We have three different explanations to this.

- Since the game Towers of Hanoi in itself can be complex and hard to solve for some people, the complexity or number of auditory objects that is possible to present is limited by the underlying model. During an early pilot study, we concluded that subjects could have problems solving the game if we used five or more discs. Therefore, we had to limit the number of objects to four. When increasing the complexity of the auditory space we might get different results. This calls for more studies of these kind of auditory interfaces where the complexity is not limited by the underlying model but rather by the limits of the sonification model and the users perception.
- Using the mouse interaction with amplitude focus facilitates the interaction with a complex auditory space. When having a limited set of auditory objects the means of interaction is more important than the way to solve continuos presentation. The way we implemented the mouse interaction increases the amount of objects and the complexity that is possible to interact with.
- The sonification model used is robust enough from being influenced by presentation mode, at least in this specific context. Again, this calls for further studies using other contexts in order to assess the validity of this specific approach

All these three explanations call for further studies. The final stage of this study of Towers of Hanoi is to make an extensive case study with blind subjects were the qualitative aspects of this auditory interface is investigated. This third study will help us understanding more about auditory direct manipulation, how it could be used and what type of applications would be interesting to implement using this paradigm.

We believe that auditory direct manipulation is indeed both possible and a promising way of interacting with an auditory interface. It will provide blind computer users with a completely new way of interacting with a computer, a way that so far has been inaccessible.

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The many rooms of the virtual workplace

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ABSTRACT

Since the mid-90's the University of Karlstad has been involved in research work on the usage of so called videotelephony in therapeutical work as well as studies in common social distance interaction. Four main projects have been presented during a five-year period:

- Videtelephony and language training for people with Aphasia
- Videtelephony and language training for people with Mental Retardation
- Videotelephony as a network tool for speech pathologists
- Videotelephony as a text telephone for people with language and speech impairment

At the moment the projects have resulted concretely in some 20 videophones installed all over the country and some international tests as well.

A main ingredient in the projects has been to study the social importance of this technology as well as the educational possibilities in the technology, that is, how learning is amplified or not through the usage of videotelephony. The final aim of all the projects is five fold. First we want to establish a well founded description of the quality of the communication situation in relation to its physical counterpart. Secondly we want to study cost-effective alternatives in the professional care of people with speech and language problems. Thirdly we want to make this technology a commonly used tool among speech pathologists and therapists in the whole of Sweden since its multi-functionality seems to offer new professional possibilities. Fourthly, we want to evaluate the methodologies which might evolve. Finally, we want to see in what ways this technology can support and alleviate the social communication patterns of the specialists as well as the service users, in other words, the people with different sorts of communication disabilities. The equipments used are in almost all cases 2x64 kb/s ISDN-based and also desktop video conferencing, that is, systems integrated into personal computers.

1. BACKGROUND

The so called Information technology has given birth to a large amount of new words, concepts and tools or products described in all languages during the last three decades or so. The most common application in the IT-family is clearly the personal computer. The grandchild of the large and impersonal mainframe-systems of the 1960's has become a sort of cybernetic mental prostheses to individuals, seemingly expanding certain mental processesses in a way which have given birth to ideas about the human machine or the technified human being. The PC as a tool is very hard to define or to classify as a tool. Most tools in human history of technology has been linear and uni-dimensional, meaning that you are supposed to use the tool in one or possibly a few general situations with very specific aims and that the result of using the tool can be seen directly. The typical tool then has been unifunctional, with one main function – the scissors will cut, the pen will write etc.

The typical tool has also been non-representative, that is, the tool has never symbolized anything. This doesn't mean that tools have never been used as symbols but the symbol-content has always been unintentional in relation to the intended usage of the tool. One example is the usage of a pen to symbolize literature, writing, being literate etc. The PC, however is multifunctional, rapidly changing, indirect and representative which makes it very difficult to define and generalize according to traditional terminology.

Still another fact which is less considered is the fact that the PC, due to its flexibility, is used by so many different groups of people and in so many different situations that the terminologies for the tool become as varified as there are different functions. In other words, the development of classification strategies, concepts and terminology is an ongoing work which is very difficult to grip. This "meta"- problem, surprisingly enough, is not debated in research society as much as would be expected. The researcher Paul Mayer has presented a short and tentative argument for a new typology for describing and analyzing PC:s where he is building upon some of the work which has been done sofar (Mayer, 1998).

The concept of distance communication also is the subject of a very intense debate, all over the world at the moment. Since large areas of the world are underpopulated and since the infra structure of communication, travel and transport is insufficiently developed in many countries, the idea that distance communication would save a lot of work (and money) is widespread today. Especially education performed over a distance has become a thing which interests people all over the world at the moment and more efforts are spent in that area than in the fields of distance work, distance therapy, telemedicine etc. People have participated in many different forms of distance education for more than 150 years (Holmberg, 1996), so the idea of a distance between teacher and pupil is not a new one. Historically the solution has mainly consisted of moving either the pupil or the teacher, bringing them physically closer to each other, until the birth of reliable and common postal communication in the early 19th century.

With modern technology, however, teaching and learning can be performed without moving the participants, just transporting the messages between them, using some sort of medium. Thereby it will be easier to raise the productivity of education in the term of number of teaching hours for every pupil and it suddenly becomes possible to analyze education in terms of marketing a product, which could be negative or positive (Peters, 1967).

To make a somewhat farfetched association, one might argue from the findings of the researcher Walter Ong (1986;1990) and say that the concept of distance in the knowledge distribution between people was born when the written language was born, in fact, that written language is the first and still most general tool for distance education. At least if we define "distance" as what cannot be experienced without any intermediate tool of some sort. If we accept this idea then we could say that the letters from the early church fathers like St Paul or St Augustin could be considered as a very early form of correspondence course.

To conclude, do we want distance communication to be a form of "virtual room" system where the meeting between people, more or less directly, is important or do we want more or less automatic systems "virtual libraries" where one person at a time is actively looking for knowledge and navigating through systems where information is stored? Or do we want both?

2. COMMUNICATION, TECHNOLOGY, EDUCATION & SPECIAL NEEDS

2.1 The Concept Of Communication

A very trendy word today is the word communication. Most definitions agree on the fact that communication consists of (meaningful) interaction between two or more participants. More detailed definitions also add that the most common tool for human communication would be language and that communication has a temporal dimension as well as a spatial, that it connects users over time and distance. To be able to create distance communication you have to communicate and also to use (some sort of) language. The means of communication today are mostly related to telematics and to computer technology. However, it is important to remember that the old-fashioned technology of yesterday, still is very much in use today. For instance, the combination of correspondence and radio-transmitted courses and exams are very common in Asian countries and radio-based education has been in use in Australia and Canada for a very large part of this century (Fleming, Toutant, 1995). The lesson to be learned from this fact simply is that new technology does not always kill the old technology, just because it is new. The price, literally and figuratively, might be to high.

The most general and optimal situation for communication would probably be the situation where the participants can use as many of their sensory organs as posible, without intermediate tools of any sort, in other words a situation where you can see, hear, touch, smell etc the one you are communicating with, in other words sharing the same experienced space or "room", at the same time. This could be described as synchronous communication or interaction as opposed to asynchronous communication of which the most extreme example probably would be reading a book.

2.2 The Concept Of Technology

The question about integrated technology vs technology with specific and limited functions – so called dedicated technology - leads us into very complicated problems. A comb or a spoon are examples of very specialized tools with highly specialized functions. The computer, however, is an example of a non-specific tool which can be used in many different ways and where even combinations of seemingly separate functions give way to new functions which makes the computer more of a mental tool, that is, the tool becomes something very close to the human mind. Finally, when the trust in the technology is strong enough, the computer might become a tool for your personality directly, a sort of symbiosis between the animate and the inanimate (Treviranus, 1993). Some authors of fiction for instance Arthur Koestler or Karel Capek and Isaac Asimov have also speculated on the fact that the ultimate tool of human beings, seems to be another human being. Would that mean that our technological motivation, deep down in our collective Jungian subconscious mind, would be to create something in our own image, in other words to play God? Or just to create a child?

One of the big discussions of educational technology today concerns the question of the relation between form and content. The philosopher MacLuhan stated that "the medium is the message" in his classical book the Gutenberg Galaxy, stating that the mass fabrication of the written word forever has changed the thoughts of people. In other words, our thoughts become dependent and variable according to the medium whereby we express them. MacLuhan's statement could be considered as a simplification of Whorf's theories on human language and its cultural dependency. Ong expresses several authors' ideas (Ong, 1990) when he says that the same idea can be expressed in many different ways, not dependant of the medium, that is the form. In other words, according to Ong, it is possible to express the same ideas in any medium. Ong and MacLuhan represent, or are interpreted as representing opposite ideas.

Technology has become an integrated part of human behavior today. It is very difficult to imagine a society of humans where some sort of technology would not be integrated into that society and the American philosopher Don Ihde (1990) even speculates if there ever in the history of Man has been a sort of Garden of Eden situation where Man used no technology whatsoever. The PC has become a part of telematics technology and seems to be at the core of distance communication today.

2.3 The Concept Of Education

This concept includes a situation or a specific environment, an activity or several activities and some participants. In this situation there is a meeting between the participants where they act jointly. This activity is goal oriented towards a problem to solve, an item of information to remember or a question to answer. Those three goals are different parts of the general concept of learning which is the main goal of education, according to all educational models. However, the three goals are very disparate which means that the idea of learning is a complicated one where there is no direct consensus in different cognitive theories. That sort of discussion has no place in this paper, suffice it to say that learning is no "watertight" idea or concept, but that memory and performance are central parts of that concept.

If we tie modern ideas and definitions on education together, there seems to be a need of a technology where participants can interact and use as many sensory channels as possible and where it is possible to interact with many in the same way as with few, and where language knowledge is important. Furthermore, it is important to realize that communication can be both synchronous as well as asynchronous (Zirkin, Sumler, 1995).

2.4 The Concept Of Special Needs

Not so many years ago we tended to talk about "handicap" and "handicapped people", meaning anything and anybody with some sort of (physical, mostly) deviation. Since the 1960's and WHO's definition of the concepts of impairment, disability and handicap the debate about human rights and society's responsibility and the role of the individual etc has been much clearer. In the 80's, however, the ever-ongoing debate was coloured by the fact that the rapid technological development would interfere with the lives of many more people than expected from the categorization made by WHO. For instance, elderly and people living in desolate areas and other groups would be very much marked by societies willingness to adapt to and adopt new technology. The general ICIDH-concepts used today are based upon social and functional as well as biological considerations

This problem of words and concepts is important on another level. Groups of people with disabilities, within or without their organizations have rightly commented on the fact that when we talk about disabilities and when we create new concepts and words, then it is very rare to find people with disabilities involved (Seale, 1988; Johnson, Moxon, 1988).

3. DISTANCE LEARNING & DISTANCE THERAPY

3.1 The Telematics Or Distance Learning Situation

The first real studies in the educational situation in electronical distance education were made
In the 1960's and 70's. The most wellknown studies were made by the American sociologist Roxanne Hiltz Starr (Starr, 1995). She used the concept the "virtual classroom". If we accept the ideas mentioned above that education should include interaction, then a main part of distance education would be to stress the sense of

being interactive, for the teacher as well as for the pupil. From the experiences of earlier trials with distance technology, it is clear that a tool that uses only limited channels of communication has been enough to create interaction and contact, both between individuals with special needs (Cerf, 1996) and anyone who is using a distance tool.

If we accept a basic idea that a human being has the optimum chance to interaction and common understanding and contact, in a situation when you feel close through as many channels as possible, then it is highly probable that the usage of a technological tool which offers as many channels as possible will result in the experience of high quality (and quantity) communication. A concrete example of this is the many trials all over the world, investigating videotelephony as a communication tool (Brodin, Magnusson, 1993). A recent study in Sweden at the University of Karlstad estimates that there are at least 500 large video-conferencing studios available in Sweden today and that the number of desktop systems using either analogue communication or ISDN can be counted in thousands. It is very difficult to find solid studies on the longitudinal usage of videotelephony. Since Norway is one of the "videophone-densest" countries in the world we have to mention one of the few available books on collected experiences of videotelephony (Kristiansen, Ed, 1991).

3.2 Distance Education And Special Needs

The first systematic trials, using telematics were started in the 1960's and 1970's. If we mention a few examples, for instance in delivering medical and pedagogical support regarding disabled children in rural areas in the US, including direct training to the children themselves (Aeschleman, 1979). Another example was a very concrete projet in the US where Stroke patients had specific training to handle the telephone (Leff, 1976). A third example was a system to give consultations to communication impaired people over the telephone, also in the US (Vaughn, 1976). Some of the earliest trials with graphic phones for deaf people came already in the mid 70's (Pearson, 1981). The earliest trials used the telephone or radio, later on TV.

In the 1980's the concept of telemedicine was created and most applications directed towards experts in the distance communication field and special needs are defined as being part of telemedicine today. An immense number of experiments are conducted all over the world with the main goal to teach experts how to use and benefit from the technology. Today, the main technology in use in telemedicine seems to be videotelephony. One of the early pioneers in seeing the possibilities of telematics for a specific group of users was the American speech pathologist Robert T Wertz who studied potentials of telematics for consulting in the Stroke and Aphasia fields in rural and remote settings in the 1980's (Wertz, 1992). Another example with telematical consulting included tests with a specialist available over the phone for talk and text (Dean, 1991; Goldberg, 1997). In Sweden the Swedish Handicap Institute and the Telecom company had a joint project on telematics and disability. Within this project a lot of research was produced and also reports of great principal importance, for instance inventories on ongoing activities and needs for the future (Lindström, 1989).

The examples from the 1980's and the 1990´s have developed into two main directions, as mentioned above, the "virtual classroom" or the "virtual clinique" direction and the "virtual library" direction. The technology representing the virtual classroom would be videotelephony and the other direction could be represented by Internet. However, the technologies and directions tend to mix between them so for instance, you can use simple videophones over Internet and it is also possible to simulate some sort of virtual classroom over Internet.

There have also been trials for people with special needs to give distance education, for instance to people with Aphasia (Lifvergren, Lundell, Magnusson, 1997, Holand 1991, Magnusson, 1995, Johansson, Magnusson, Wallin, 1997). The last example also gives descriptions on how to teach or train adults with mental retardation. The tool in this case is the videophone or Internet and the results are preliminary very good. However, there are also projects which have resulted in more skepticism.. At the Microelectronic Institute at the University of Dundee, under the leadership of professor Alan Newell, there are always ongoing investigations into the use of different sorts of technologies. In 1994 they looked into the use of desktop videotelephony and found that technology was not transparent (Beattie et al, 1994).

These few examples clearly show that the area is very heterogenous and that distance education can be defined as multimodal, which could mean several things but I choose to interpret this information as a recommendation that designers of courseware must be open to combinations of methods or integration of technologies and an awareness that technology should never be an end to itself.

3.3 Distance Therapy

The concept of therapy is very close to the concept of education. In both cases you use certain methods to make a person or a group of persons change. In education you expect more of a development but in therapy or treatment you often expect a more radical and definite change from one state of being into another. The main difference, however, is the fact that when you need therapy or in other words treatment, you are presumed to lack some necessary part in your body or personality which you have lost from illness or accident.

Before you receive the treatment you are diagnosed by an expert who then suggests a plan of action or treatment, the diagnosis, which then could be perceived as a part of the therapy, which in general is performed by members of the medical profession in much the same way that education is performed by professional educators, mostly teachers. In distance ducation, then, people talk a lot about one main type of activity, that is the situation where the teacher teach and the learner learn, that is the classroom-situation. In distance therapy or rather telemedicine which has become the main concept, we rather look at a situation of many different activities which together form the concept of telemedicine (Akselsen, Eidsvik, Folkow,1994, Olsson, 1997). The main parts of medical activities then, would be three: diagnostics/ analysis; therapy or treatment; and prescription.

In all of these subareas, certain telemedical activities have been developed and evaluated. The main efforts have been spent in the diagnostics field where methods for fine diagnostics over a distance have been developed in most of the major clinical fields. X-ray pictures of broken legs at ski-resorts are transmitted over ISDN-lines from local hospitals to central expert hospitals which can make a diagnose and suggest the treatment without having to travel to the patient or vice versa. Gastroscopy can be performed over the same network and also otolaryngological investigations (Goldberg, 1996). Making a good diagnosis is dependant on deep and highly specialized knowledge in certain areas and some medical developpers are trying to create AI-based expert-systems to support clinicians when they make their diagnostical work (Olsson, 1996).

Telematical treatment or therapy is much rarer. Some work has been done in the psychiatry field with therapeutical discussions over videophone-lines (von Tetzchner, Holand, Steindal, 1991), more on the line of giving support to the local staff. Long-time trials have been made with language training for people with Aphasia (Magnusson, 1996) and also short-time trials (Peters, 1996, Holand, 1991). Most of the results indicate that the technology has its faults and that it is difficult to experience that the intermediate technology is totally transparent, for the patient as well as for the therapist. A very special telematics treatment work has been done in several places in the world, using computer transmitted messages to portable pocket telemessengers, used by people with memory problems, both from senility and traumatical brain injury (Hersh, 1994).

3.4 Distance Therapy For People With Aphasia

In Sweden there was a longitudinal project with people with Aphasia for 20 months and 31 persons participated. The participants spent a total of 20 sessions together with me over the videophone, receiving language training according to individual training plans. They had different types of Aphasia and were categorized according to the three main groups Broca, Werniche and Global Aphasia. The results were analyzed mainly from the perspective of the participant, that is, whether they found the sessions and the medium satisfactory.

The main result shows that no participant found the medium totaly dissatisfactory, that most participants found no major differences in quality betwen the medium and so called physical real life interaction. Some of the participants also experience that their language ability is becoming better through the sessions and some also would like to use similar technology to alleviate their private communication. Most of the participants describe the main results of their experience with the technology as “a situation where they learnt something”. Some of the main results indicate that users tend to oversee with the quality problems after a few times usage and that the basic comments on the technology have to do with the correlation between the visual and the auditive channels. Users very quickly learn different strategies for communication and experience a higher quality of interaction after some time of usage. However, initial comments often express a mixture of disappointment for the quality and if there are any expectations at all, they are very much coloured by experience of TV.systems,

4. PROFESSIONAL NETWORKS: VIDEOPHONE COURSE, TELELOG 1-3, REGLOG

Speech pathology in the general sense is a vast professional field, where many projects have been developed during the years, including technological applications. The field of AAC (Alternative and Augmentative Communication) has inspired a large number of technology projects all over the world and in latter years these have focused on telematics projects, but projects involving videotelephony are fairly new in the speech pathology field.

In Sweden there are approximately eight hundred speech pathologists out of a population of 8 million. Forty individuals or 0.5% of them are male so the group could be considered as mainly female. Most of them are working in the big city districts which means that the more unpopulated areas of Sweden, which would correspond to about two-thirds of the country's geographical area are understaffed. For instance this effects about twenty per cent of the population in the northern part of the country, or seven of the 24 counties of Sweden. Speech pathology is a (para)medical profession and the medical services are mainly the business of the county councils while higher education and research is the business of the State and managed centrally. This means that undertaking research activities in the medical or care field can be difficult to organise. However, most local counties support research in co-operation with their closest university or university college. There are also a few university hospitals in Sweden, situated close to the original five old universities of Sweden. There are four schools for speech pathologists in the country, including the one at the Karolinska Institute.

In 1997 Värmland County Council (where Karlstad University is situated) started the TELELOG project, partly with financial support from the EG. The aim has been to teach all speech pathologists within the County to use videophone equipment as a natural part of their intra-professional relations. The results of this project will decide on the future use of the technology as a more integrated part of the therapeutic part of the work of speech pathologists.

During most of that time, the Karolinska Institute has managed a course for speech pathologists on computer technology which one of the authors of this paper led. The course has given over twenty per cent of all Swedish speech pathologists a basic knowledge of information or computer technology. During the TELELOG 1 period the same institute, the college of speech therapists in Stockholm has managed a post-graduate course on the subject of telematics and distance communication for speech therapists. The course covers 5 Swedish academic credits and provides basic knowledge on the theory and practice of telematics and different methods of distance education. Forty per cent of the lectures have been transmitted over ISDN using videophones.

TELELOG 2 studies the interaction between a few people with severe communication problems and their spouses and rehabilitators. One of the users has traumatic brain damage and another has a global Aphasia. The third participant user has CP and uses AAC-communication. A local Aphasia chapter is also involved and a folk high school with a rehabilitation course for people with Aphasia. The reaction of the users so has been overwhelmingly positive and two of the participants have decided to keep the equipment at their own cost..

Another project which is in its initial stage is called REGLOG. The northernmost college for speech pathologists is situated in the city of Umeå, not far from the Polar Circle. During the basic training of speech pathologists, videotelephony shall be used as a tool. The person responsible for the speech pathology school in Umeå is ass. Professor Ms Elisabeth Sederholm. The project is planned to develop a network over three years, including all speech pathologists in that part of the country. So far, four systems are installed and another five systems have been installed in the northernmost county of Sweden in the autumn of 1999, within the framework of a third TELELOG-project.

There is a common technology and methodology in all of the projects. First of all the common user group is speech pathologists, specialists in communication and problems with speech and language. Secondly, the aim is to develop professional networks, that is, the communication will be very goal-oriented. Thirdly, the technology is desktop-videotelephony meaning that the videophone function is integrated in a standard PC and can be combined with any other of the functions of the PC. Fourthly, the network used is ISDN which is an open network. In other words, a standardised technology is used in a natural environment.

Within TELELOG 3 there will also be a comparative trial of Aphasia therapy with and without videotelephony. This trial will run until December 2000.

About 40 speech pathologists and 20 students are or will be involved in these projects. So far, 25 professionals have been involved and the response has been very positive. The participants rapidly develop user patterns where they interact on a regular basis with their colleagues instead of using the phone or meeting physically. Some interactive work has also been done, mostly writing texts together, sharing word processing software between two users. People have also attempted to share therapeutic software, thereby simulating a session with a patient. The next step will be to try and practice therapy through the videophone. The main problem has to do with the experienced conflict of priorities between having to choose between the computer and the patients. However, all participating speech pathologists have also been allowed by their employers to take time to participate in these experimental projects.

Among the negative comments have been reflections on the necessity to integrate the usage into a meaningful everyday situation and also the need to have extra service personnel available, especially for group calls. However, the negative comments are rather few.

4.1 Tentative User Comments On Analogue Technology

A few experiences with analogue systems using narrow band have been made, both with dedicated equipment as well as with PC:s using Internet software. In the few cases performed the main reaction could be condensed into the comment “It’s nice to see someone like this but compared to ISDN or TV, what’s the use?”.

5. CONCLUSION

Most users still are in a stage of fascination with the possibilities with the technology. Few of them have however gone on to the stage where they develop routines and where the technology is safely integrated into the workday. Most users talk about the future when it will be established. Some of them can see less travels and more fun and also more usage of their PC:s. This is just the beginning and data has to be collected for years to come at the same time as the technology will have to be spread to more and more users. The vision of the virtual room is not a reality so far but people can easily understand it and some are fascinated by it, others are worried but there is no fear among the users.

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Research and education activities on disability and disabled people at the Virtual University in Nordic countries

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ABSTRACT

This paper describes the practical implementations and possibilities of virtual university for research and education on disability and disabled people. The development of internet technology supports the practise of this mission. In the late 1990s the Finnish Network for the Research on Disability (*http://www.jyu.fi/~vamtutk/lomake.html*) and the Nordic Network on the Disability Research (*http://www.harec.lu.se/NNDR/index.html*) were founded. The members of these networks are mostly non-medical disability researchers and authorities in Nordic countries. With the help of internet technology these networks together are building the virtual university, where it is possible to study disability issues. For example the internet based network makes possible to give a study counselling on-line easily between Nordic countries (Denmark, Finland, Iceland, Norway and Sweden). In these countries several disability organisations and universities are the members of the virtual university project. The development of virtual university and study programmes are coordinated by the board of Nordic Network on the Disability Research (*http://www.harec.lu.se/NNDR/members.html*). So far practical examples are the annual Nordic conference on disability research since 1997, the first doctoral course in 1999 and the publication called "Scandinavian Journal of Disability Research" (*http://www.harec.lu.se/NNDR/activities.html*) since 1999. Besides these activities all the information and advisory services are available via internet and mailinglist. (*http://www.jyu.fi/~vamtutk/tietopal.html* and *http://www.harec.lu.se/NNDR/mailinglist.html*). A long term goal is to wide this project from Nordic countries to other European countries.

1. INTRODUCTION

This paper describes the practical implementations and possibilities of virtual university for research and education on disability and disabled people. The development of internet technology supports the practise of this mission. In the late 1990s the Finnish Network for the Research on Disability and the Nordic Network on Disability Research were founded. These flexible organizations are ensuring the development and activities of the Nordic Virtual University. First we present the structure of the University. Second we shortly grasp the main theme of the Virtual University reasearch subject that is "disability organisations as social movements".

2. THE STRUCTURE OF NORDIC VIRTUAL UNIVERSITY

The Finnish Network for the Research on Disability was founded in Jyväskylä 1996. The purpose of this network is to get together researchers, institutes and organisations on disability. The main task of the network is to promote the cooperation between disability researchers of different disciplines at the national level. Thus the network is organising scientific conferences and smaller meetings, informing about disability research projects and promoting international cooperation. A technical instrument of the network is The Foundation for Research on Disability, who provides internet and e-mail connections.

The Nordic Network on Disability Research were founded in Fredrikshavn 1997. The purpose and intention of this association is to promote and advance research and development in the field of disability, including creating opportunities for presentation and publication of such research. The association's area of activities and operations is the Nordic countries.

The members of these networks are mostly non-medical disability researchers and authorities in Nordic countries. So they mostly are representing psychology, social sciences and history. With the help of internet technology these networks together are building the virtual university, where it is possible to study disability issues. For example the internet based network makes possible to give a study counselling on-line easily between Nordic countries (Denmark, Finland, Iceland, Norway and Sweden). In these countries several disability organisations (e.g. Finnish Federation of the Visually Impaired and Finnish Association of the Mentally Retarded and universities (e.g. University of Jyväskylä and University of Stockholm) are the members of the virtual university project. The development of virtual university and study programmes are coordinated by the board of Nordic Network on the Disability Research.

So far practical examples are the annual Nordic conference on disability research since 1997. The first conference was in Fredrikshavn, the second one was in Jyväskylä and the third one in Trondheim. This year's conference is in Malmö. Themes of the conferences have dealt with the quality of life and the challenges of the new millenium of disabled people. The first doctoral course was in 1999 and there is a publication called "Scandinavian Journal of Disability Research" (SJDR) since 1999. SJDR is published by Nordland Research Institute on behalf of Nordic network on Disability Research (NNDR), who, in addition to the journal, also organise yearly conferences. Members of NNDR receive the journal free of charge. At a conference in Fredrikshavn in 1997 a new network - Nordic Network on Disability Research - was established. One of the purposes of this network is to establish a journal in English about social research on disability: Scandinavian Journal of Disability Research. Its main purpose is to disseminate results from social research on disability. Social research is - in this context - including for example educational sociological, socio-psychological, historical, legal, economical, socio-medical research. Its defining characteristic is a focus on the relation between persons with disabilities and their environments in a broad sense. Although the ambition primarily is to encourage Scandinavian researchers to submit articles for publication, the Journal welcomes articles from all over the world.

The editorial board hopes that the Journal will stimulate researchers to consider the Journal as an appropriate arena for publishing their research, as well as teachers, students, professionals and disabled persons and their organisation to realise the worth of this channel for disseminating research.

The financial background of these activities is mostly coming from the Nordic Academy for Advanced Study (NorFA). NorFA is a supporting organisation of research education and Nordic Council of Ministers is liable for it. Other activities are the financing of doctoral courses and mobility scholarships, research networks etc. Other financial sources are member-universities and other associations.

Besides these activities all the information and advisory services are available via internet and mailinglist. A long term goal is to establish a permanent faculty on disability research and education and wide this project from Nordic countries to other European countries.

Figure 1 shows the current situation of virtual university that we have pointed out in this paper.

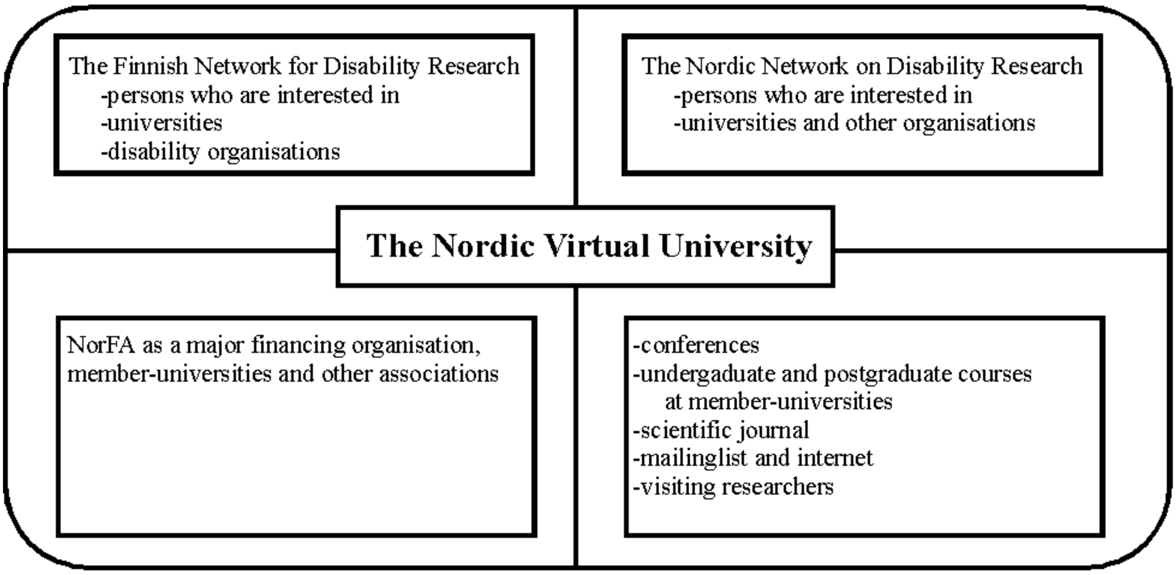

Figure 1. *The network structure of the Nordic Virtual University.*

3.THE SOFTWARE

For the e-mail and internet connections the software is as follows:

3.1 The Majordomo System:

Majordomo is a program which automates the management of Internet mailing lists. Commands are sent to Majordomo via electronic mail to handle all aspects of list maintenance. Once a list is set up, virtually all operations can be performed remotely by email, requiring no intervention upon the postmaster of the list site

Majordomo controls a list of addresses for some mail transport system (like sendmail or smail) to handle. *Majordomo itself performs no mail delivery* (though it has scripts to format and archive messages).

Here is a short list of some of the features of Majordomo:

- Supports various types of lists, including moderated
- All list management activities are handled by email, so list owners don't need access to Majordomo server machine
- Supports archival and remote retrieval of messages
- Supports digests
- Modular design - use only the features you need
- Written in Perl - easily customizable and expandable
- Includes support for FTPMAIL
- Supports confirmation of subscriptions, to protect against forged subscription requests
- List filters, based on header or body regular expressions

3.2 The Internet System

Here is a short list of the services are including (an example in Finland)

- Internet connection using a modem or ISDN (1 or 2 channels)
- Or, by GSM (cellular phone):
    - Internet services can be used with an Internet cellular phone (not WAP!) or with a normal cellular phone attached into a computer.
    - Radiolinja connection should work with our numbers 1079001, 1079003. and 0600-9-4003 (in Finland).
    - Sonera connection works only with number 4499001 and 0600-9-4003 (in Finland).
- Modem-, ISDN- or cell phone connection includes: routing of IP traffic using a dynamic IP-address with PPP- or SLIP-protocol, through the chosen telephone connection to customer's computer. Customer is only entitled to reroute the traffic locally inside their own organization.
- Another alternative is a fixed monthly charge, which allows using the number 4499001 without an additional charge (over normal phone charges).
- E-mail:
    - Pine- and Mutt- e-mail programs, and POP/IMAP- and SMTP- e-mail services on our server.
    - Option to use "*forename.surname@co.jyu.fi*" -type of e-mail address.
    - E-mail alias (mostly for businesses and societies), for example "*business@co.jyu.fi*".
    - Mailing lists
- Reading and posting into Usenet News
- WWW home page
- Using own CGI scripts on WWW pages
- FTP file transfer
- 10 megabytes of disk space on server

3.3 Additional services

- Additional hard disk space, according to separate contract or current prices

- Domain, for example "*www.business.fi*"
- Domain parking: you can reserve a domain name (including .net, .com, and .org -domains) and park it here for later use.
- Fixed connection: 2- or 4-wire connection, fixed copper, optic cable, radio or microwave links; also, ADSL is coming in the near future.
- Statistics: automatic ftp-, web-, etc. statistics.

4. THE RESEARCH SUBJECT OF VIRTUAL UNIVERSITY

As we have mentioned earlier the research activity is in social sciences and so the main subject lately has been "The position of third sector in a service process of disabled people when the relations between welfare actors have changed during the 1990s". The critical social study can be focused on a power analysis. The attempt is to address a power analysis to the situation, where disability organisations are representing the third sector and consequently they have a (political) relation to a public sector. There is a good reason to perceive service processes of disabled people as a reciprocal dependence and a power relation between authorities and clients. These two parties are searching some kind of balance as macro social changes are happening. Transitory balances can be named as figurations (van Krieken 1997) that are processes of bio-politics (Foucault 1988) in governing practices especially when our focus is disability services. To put it simply in service practices people's biological and mental characters defining their social conditions.

Disability organisations work together with public organisations, but disability organizations' work has contingential tendencies, because those unofficial social networks that they are involved are flexible to different situations or should be at least. Thus the flexible social network is an opposite to organisations of public welfare services. Flexible social networks can easily complement public services right now after the recession of the 1990s. Social networks are side by side or even alternative with a public sector. This tendency has changed a character of a welfare state from a state-run principle to an emphasizing of clients' iniative potentiality and basically alternative services have increased. The relation between a public sector and surrounding social network is defined and re-defined all the time. That is why this relation is contingential and flexible. These features are including Elias' (1978) view of processes that are based on people's interdependence (power relations) and that's why processes are more intentional than rational. In these processes some economical, political and military player always has a dominance, but it is only one figuration that is not a static situation. The power relation should be understood as a interdependence of macro and micro social processes that are changing the world (cf. The Giddensian structuration theory [Giddens 1984]).

The contemporary dominance of service processes for disabled people is compressed in governmentality. This Foucauldian (Foucault 1988; 1991) term represents the techniques of power and its practical form is above mentioned bio-politics in a thruth production that is focused on subjectivity. In a case where the system's outside disturbances are notified, the new bio-political techniques of power are developed in modern society. That means e.g. new or renewed medical diagnoses and new definitions of possibilities in social life with disabled people. The whole governmental system (public social services) in Nordic countries seems to be very predestined for disabled people. However the system as a whole is not so repressive as we are thinking about subjectivity. Foucault (1988) emphasized the meaning of self-techniques as one possibility of subjects to gain their goals in modern societies' power techniques. I would say that these self-techniques are consist of system-oriented services practices, but also interdependence of different service organisations and people (clients and servants). All in all the final practices of services are the outcomes of complicated non-predictable processes.

5. CONCLUSION

The subject of this paper has been an example of the Nordic cooperation on non-medical disability issues. Today this development takes its early steps, but we believe that new technological advantages make also social issues of disability research and education easier to reach. The social dimension of our well-being to combined new technology is the only way to improve humanity.

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Finnish Network for the Reasearch on Disability: *http://www.jyu.fi/~vamtutk/lomake.html*

Nordic Network on Disability Research: *http://www.harec.lu.se/NNDR/members.html*

NorFA: *http://www.norfa.no*

Psychological and pedagogic testing of handicapped children with locomotion disorder using multimedia programs

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ABSTRACT

We have developed a multimedia-testing program, which helps the testing of cumulatively handicapped children and is specially designed for the testing of handicapped children with locomotive disorder. It has been prepared for the Commission of Investigation and Rehabilitation of Locomotion Disorders and the Centre of Teaching Handicapped Children. The psychological part of the program is the RAVEN test. The pedagogical part of the program contains several tasks the child will find as a playing possibility. Our program had to been developed in such a form that it could be used also by handicapped children with locomotive disorder.

1. INTRODUCTION

The Commission of Investigation and Rehabilitation of Locomotion Disorders and the Centre of Teaching Handicapped Children asked us to develop computer test programs that can be used in investigating the capabilities of handicapped children even if they have locomotoric disorders.

The psychological part of our multimedia-testing programme uses the computerised version of the RAVEN test. There are already other computer versions of the RAVEN test, but these are not suitable to test handicapped children with locomotoric disorders. The problem is that children with locomotoric disorder are unable to perform fine movements as needed to work with a mouse or a keyboard. A program has been designed that is much easier to use.

Our pedagogic aim was to deal with questions of form, colour identification, the investigation of mathematical knowledge.

In the present paper we will show the complex testing tasks of the commission, pointing out for whom the programs have been developed and we will give a short demonstration of the programs. The oral presentation will deal with the results of using the program as well.

2. TASK OF THE COMMISSION IN PROVIDING RECOMMENDATIONS

Every country deals with the education of handicapped children. This is, however, different in different countries, depending on their tradition, law making coustoms and economic strength. These guidelines reflect at the same time their state of economic development. At the present moment the Hungarian school system undergoes permanent changes, parents can now choose between a high number of educational school systems. In 1993 a new Law of Compulsory Education was accepted, which extended the compulsory education also to children who can not taught in the traditional form. Compulsory education is between the age of 6 and 18, but this can be extended for children with locomotoric defects till their age of 21. The National Rehabilitation Board descides on the starting of the compulsory education, on its extension the teacher's board and the Board can decide.

The co-workers of the National Expert Board form a team. Members of this team are physicians, psychologists, and teachers of handicapped children, physiotherapists, teachers and conductors. This team has the task to investigate the children by the help of complex medical, psychological and locomotoric investigation. The testing deals with:

- the mental capabilities of the student for learning
- their ripeness
- their speech
- their capability of arranging things around themselves
- their capability of moving.

Based on this input data and checking also their environment the team has to make recommendation on the type of educational institution the child should attend.

Handicapped children with different types of handicaps can deal with their compulsory education in different school systems, depending also on their mental state of health:

Children can get special education, teaching if:

- they are handicapped in learning,
- if they are mentally retarded,
- if they are both mentally retarded and have severe locomotive disorders.

Those children, who have difficulties in their movement and can not attend the special ground educational schools of their locality, can attend special institutions designed specially for handicapped children with locomotive disorders.

The Law of Public Education is a positive step forward, it deals also with those children, who are in the age of compulsory education but have been regarded as non-teachable mentally handicapped having also locomotoric disability. Children with severe mental problems and locomotorically handicapped are not taught at present in schools similar to normal schools but get pedagogic training specially adapted to their needs. This is called by the law "compulsory instruction". It can be individual instruction or done in small groups. This type of instruction is provided both for children who live in families or who are in a social or other institution run by a Church. As mentioned the instruction is normally for children in the age between 6 and 18 years, but if necessary it can be extended based on the recommendation of the Expert and Rehabilitation Board. Before the child gets into a course it gets tested by the Expert Commission. Based on this diagnostic test an instructional program is set up to work out the positive features the child can deal with.

It is difficult to test the capabilities of mentally handicapped children with locomotive disorder:

- it is difficult to establish the necessary mutual communication ,
- in front of the team they get into a new situation and the new and foreign environment can have negative effects on their mood.

Due to this the major form of their testing is their study. This can be extended by using different question forms, using test scales and other tests. Besides of this it is very important to investigate the environment of the handicapped child.

The instruction programme is set up according to the recommendations of the Expert committee, it is extended by further programs of locomotive instructions, logopedia, hydrotherapy, etc. This instruction programme becomes part of the normal tutorial year, it encompasses at least five hours of instructions per week. It is financed by the state fiscal programme. The financial means are supplied via the educational institution. The Expert Commission provides instruction also for children living in families by sending teachers of handicapped children and conductors to the families.

The effectiveness of the education, instruction of children with locomotive disorder is most effective if started at an early age. Therefore the Board checks the children with locomotive disorder starting at the age of three years. If requested they perform also control investigations. The diagnosis always contains information on the capability of moving, the mental status, and eventual further disabilities and contains correction advises. Based on this expert advice the parents of the handicapped child have to decide on the possible schooling – taking the present possibilities into consideration.

From the above it can be seen how complex and full of responsibilities it is to decide on the fate of a child. Our complex computer test and tutorial programs are to help this work and to make it more objective. The first step into this direction is the computer program we introduce in this paper

3. THE PROGRAMME

3.1 The psychological test of the programme, the RAVEN test

The RAVEN test is a perceptive, non-verbal test to investigate the intelligence of the child. Factor-analysis has shown that the general intelligence correlates mostly with the understanding of the perceptual, non-verbal relations. RAVEN (1938) formulated the theory in his test series called „Progressive matrices. RAVEN and his co-workers standardised this test in Dumfires in 1949, based on investigations performed on 608 children in the age of 5 ½ to 11 years. Their results have been summarised in a table showing the percentile points for groups of six months intervals.

Task of the investigation: the empty part of a picture with a figure has to be filled in. The picture shows a regular pattern or figures in two dimensions (vertical and horizontal). The correct response supposes that the test person realises the structure of two rows and selects the correct pattern to fill in the empty space. This means that he or she has to realise two ordering principles, has to comprehend the regularity of the pattern or has to find out the proper sequence of the sub-patterns or figures. To complete the test the test person needs to perform complex logical tasks.

Details of the test: The test contains 36 tables. On every table in the upper part the picture is seen, in this picture there is a part where the structure is missing (missing unit). This missing part has a well observable border. Below the picture there are a number of smaller units of the same size as the missing unit in the picture. These units have different internal structure and the task of the test person is to find out the unit that has the same structure as missing in the main picture. (See Figure 1.)

The units, from which the test person can select a unit, are numbered. The test person has to state that number for which he/she thinks the pattern of the unit will fit the empty square in the main picture. (As the multiply handicapped child might not know the numbers, he or she can point onto the fitting square. But a child with locomotoric difficulties might not be able to point to a unit. Thus the RAVEN test can not be used with them in the traditional fashion. This has been considered when the computer version has been developed.) At the traditional test the test conductor makes written remarks on the test sheet, he/she takes notes on the number the test person has selected. The programmed version fills in the test sheet automatically. The 36 tasks are subdivided into three categories. The categories are enumerated with the letters “A”, “AB”, “B” and carry the numbers 1 to 12. The first task is thus A1, the last one is B12.

The group A contains pictures with homogeneous structure. The test person can select the unit that corresponds to the empty square by inserting the unit into the square. There are six units from which the test person has to select the unit with the correct pattern (see Figure 2.)

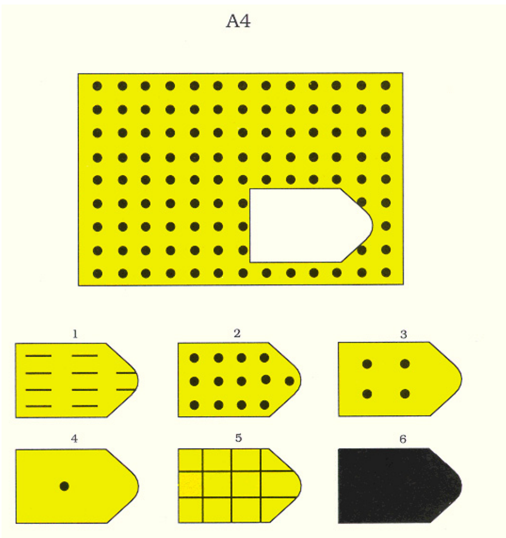


Figure 1. *A task from the RAVEN test.*

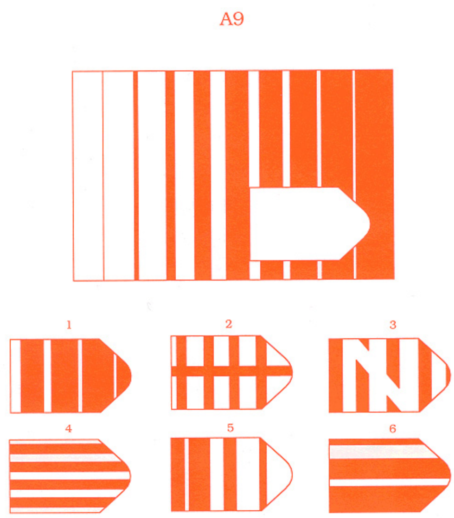
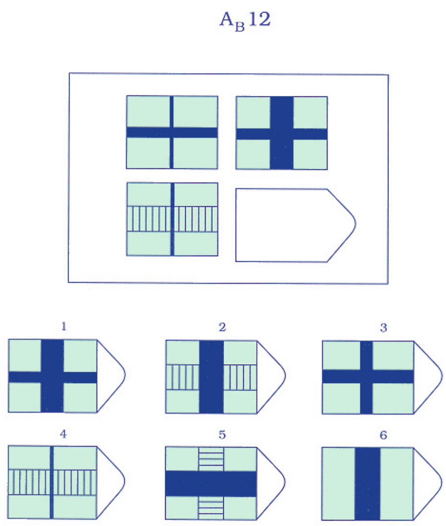
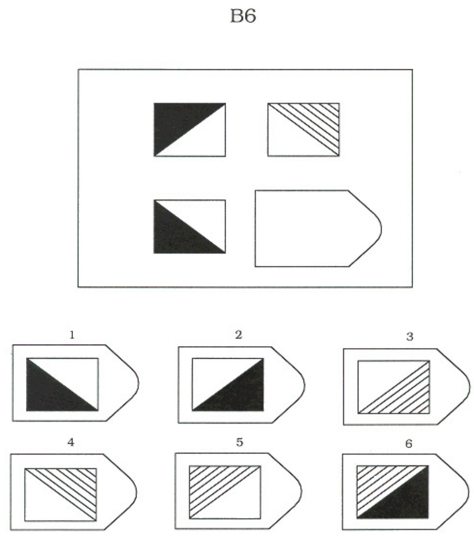


Figure 2. *Sample from Group A.*

Groups “AB” and “B” contain pictures that are composed from four units. In the first three tasks of the groups four-four units are the same, in the following ones the four units together form a logical order. The selection can be performed from six units (see Figures 3. and 4.). All three groups start with simple tasks that are easy to perform. But in every group the task become more difficult as one progresses among the tasks.

The groups themselves are also arranged in order of difficulty. The author has chosen this arrangement, because he found that the test persons learn in doing the experiments.





Figures 3. and 4. *Examples from the Groups "AB" and "B".*

Performing the investigation: We use the test with children of age 5 to 11 years. The standards provide indications for children of 5 ½ years of age on. The investigation is done in individual tests. We start the program. At the beginning the children still do not realise what the result will be when they insert the selected unit into the picture, and they are not very cautious in their selections. The conductor of the experiment has to tell them clearly what their task is and keep them alert to perform the task correctly.
The RAVEN test in its form developed by us is similar to the traditional one. The main difference is that the handicapped children with locomotoric disorder are unable to use the mouse or the keyboard of the computer. When the new test frame appears the computer waits for a keystroke. This can be any key on the keyboard or even on the keyboard of the special Intellikeys keyboard. This provides ample time to look at all the units from which the child can select. Then the units fade and always only one is highlighted. The test person has to signal that just the right unit is highlighted, when he or she thinks that that unit should be inserted into the main picture. The test does not record the time, thus the test person can wait for several fading and sequential highlighting cycles. (See Figure 5.) At the end the program provides attest sheet similar to the sheet filled in the conventional test by the test conductor. The fading and highlighting speed can be adjusted.

The comparison of the test result sheet with results obtained using control groups and the traditional test, are in progress, the oral presentation will show some results.

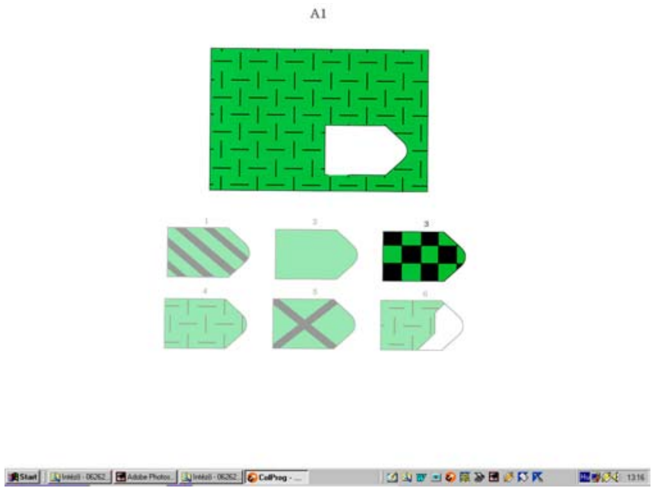


Figure 5. *Examples for the fading.*

3.2 The pedagogical investigation part of the program

The pedagogical part of the program contains several tasks the child will find as a playing possibility. It consists of four major parts:

3.2.1 Tasks similar to those of the S.O.N. tasks. The fists part contains tasks similar to those of the Snijders – Oomen test. They contain non-verbal intelligence test. They are grouped around a main program called "story-tree". Parts of it are: Pictures that belong together, analogies, sorting tasks, combinations, memory tasks, filling in, ordering pictures. After selecting the task type we get into a room, where we can select to move into task A, B or C. There is a small picture of the story-tree on the wall, this signals that we can get back into the main menu by clicking it (see Figures 6 and 7). Due to place limitations we will deal here only with some examples.

Figures 6. and 7. *"Story-tree" and returning to the main menu.*

Pictures that are related to each other: One has to pair two groups of pictures, drawings. Thus e.g. in one group there are a closed box, closed window, closed door; in the other there are an open box, open window, open door. Thus in case of a good answer there is a symmetry relationship between the two groups.

Analogies: Here a cyclic raw is produced on the screen, similarly as in the task-plates used in kindergartens, and this raw has to be continued. Thus e.g. green rod, white rod, green rod, white rod, green rod etc., or red circle, red circle, blue circle, red circle, red circle, blue circle, continue.

Sorting: The elements of a set have to be sorted into to disjunct sets. Thus e.g. there are a number of circles and triangles on the screen and the task is to group them into two parts. One set should contain only circles the other triangles.

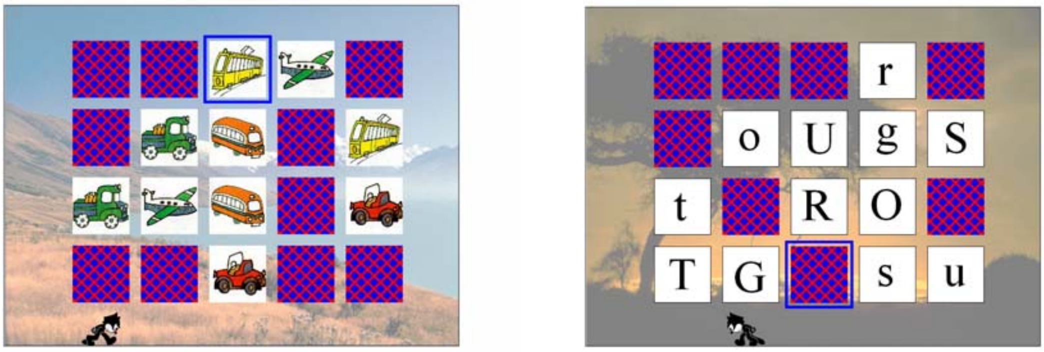
Combination: In this task a missing part of a picture has to be filled in, or from smaller parts a picture has to be build. This corresponds to the traditional puzzle toy.

Memory pictures: On the lower side of the monitor there are three hidden pictures, on the upper part there are six hidden pictures. In this task only one picture can be seen at a time. First one of the pictures is seen in the lower row, then it gets hidden again. Then a picture is seen in the upper row. This repeats itself till the child does not find the corresponding picture in the upper raw.

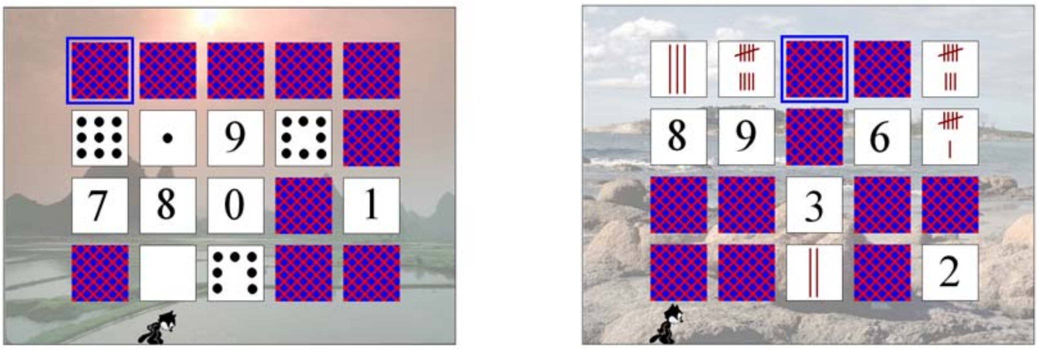
Filling in: Here first the child sees eight parts of four pictures (every picture has been halved) in random order. The task is to build the four original pictures.

Ordering of pictures: The pictures of a story are seen in random order. The task is to order the sequence of the pictures into a logical sequence. Thus e.g.: 1st picture: going to bed; 2nd picture: bathing; 4th picture: Brushing tooth; 3rd picture: dinner; 5th picture: washing hands; 6th picture: laying the table.

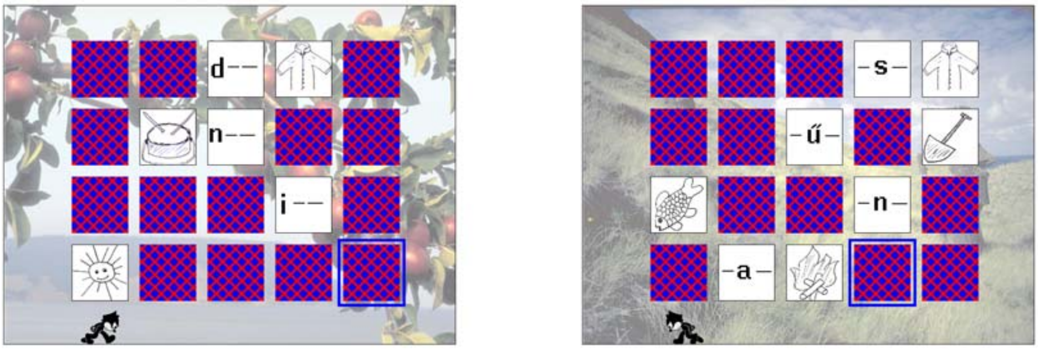
3.2.2 Memory toy. In the memory toy one has to find e.g. a picture to an other one (Fig. 8.), capital letters to small letters (Fig. 9.), number of points to the number (Fig. 10.), lines to numbers (Fig. 11.), the first character of a word to a picture (Fig. 12.), the second character of a word to a picture (Fig. 13.), the third character of a word to a picture. This part of the program contains also a toy using logical pages, where the understanding of the icons depicted on the left side of the screen is the task (see Fig. 14.) and deals also with tasks of colour (blue, green, red, yellow), form (circle, triangle, square), size (small, large), filled or empty and tasks using form-tables (Fig. 15.). In this part we have re-designed conventional form tables in a computerised form. The program shows the outlines of well known geometric or story figures, and at the bottom of the screen the real pictures of these are shown. The task of the child is to insert the proper picture into the corresponding outline.



Figures 8. and 9. *Memory toy: a picture to an other one, and capital letters to small letters.*



Figures 10. and 11. *Memory toy: number of points to the number, and lines to numbers.*



Figures 12. and 13. *Memory toy: the first and second character of a word to a picture.*

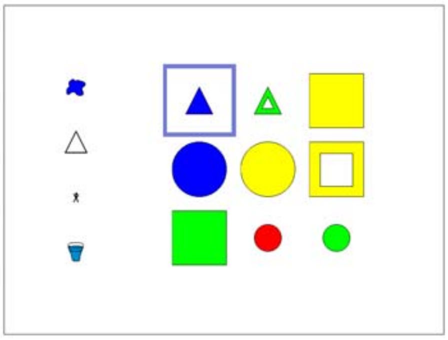


Figure 14. *Logical pages.*

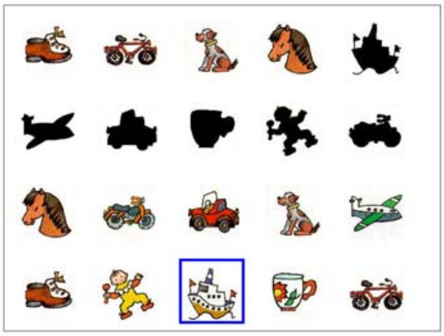


Figure 15. *Form-tables.*

3.2.3 Painting. As seen on Figure 16 the task is to paint well known objects according to the rules shown on the left upper corner of the screen. This test can be used to test the capability of larger children to understand text passages.

3.2.4 Bonus animations. The bonus animations are not part of the test task. After completing the exhausting tasks the child can choose from the bookcase an animation (see Fig. 17). These animations are based on well-known Hungarian children-rhymes.

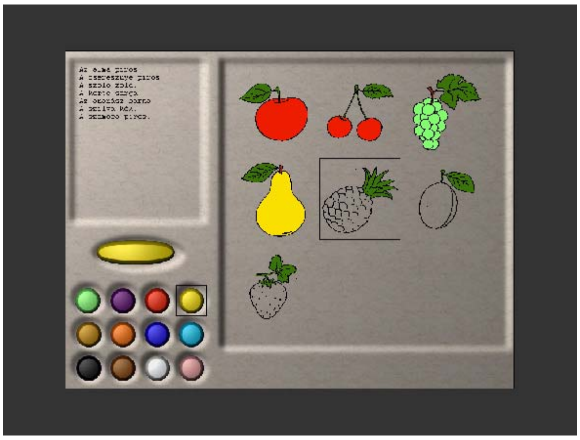


Figure 16. *Painting.*

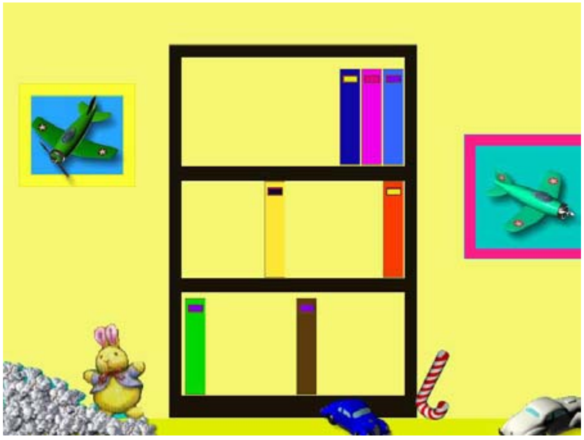


Figure 17. *Bonus animations.*

3.2.5 Results obtained using these pedagogical investigations. We test this program both with children having locomotive problems but who are otherwise of normal mental stage, and with children being multi-handicapped. The results of these tests will be summarised at the meeting.

4. SUMMARY

A multimedia test program has been prepared to test handicapped children with locomotive disorder. The problem is that children with locomotoric disorder are unable to perform fine movements as needed to work with a mouse or a keyboard. A program has been designed that is much easier to use. Our program contains a part where the RAVEN test has been computerised in form usable also by children with locomotive disorders, an other part contains test similar to those provided by the S.O.N. test, for example: pictures that belong together, analogies, sorting tasks, combinations, memory tasks, filling in, ordering pictures. This part contains also memory-toys, form-tables, painting tasks, and logical pages. At the end of the test the child can select bonus animation.

The multimedia program can be used in the entire country in testing groups. We are in the course together pedagogic and psychological feedback on the use of the program in case of different types of handicapped children. The oral presentation will show also results of these investigations. The program has been built in a form to be user-friendly, no computer knowledge is needed to use it. Any teacher of handicapped children, or psychologist can learn it in seconds. In the oral presentation we will show the complex testing tasks of the commission, pointing out for whom the programs have been developed and we will give a short demonstration of the programs. The oral presentation will deal with the results of using the program as well.

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Community access through technology project: using virtual reality technologies for community integration

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ABSTRACT

The Community Access Through Technology project uses virtual reality and other advanced technologies to produce simulations of community resources. The virtual environment is created using Quick Time Virtual Reality, and access annotations, interactive maps, and digital video are added to enhance the experience of the user. To determine the efficacy of the virtual reality in reducing anxiety, the present study was conducted. Subjects were randomly assigned to one of three groups: control group, virtual reality treatment group, or leisure education-virtual reality treatment group. Results suggest that the virtual tour increased subjects recreation knowledge but had a negative effect on anxiety levels. However, subjects in the leisure education-virtual reality treatment group experienced significant recreation information gain and reduced anxiety. Further research examining more immersive virtual environments and use of additional physiological measures are recommended.

1. OVERVIEW TO THE PROJECT

The Community Access Through Technology (CATT) project uses virtual reality and other advanced technologies to produce simulations of community leisure resources so that persons with mobility impairments may become familiar with these resources prior to visiting them in person. CATT involves:

- developing three leisure facilities, including the 20th Street Recreation Center reported in this study, into virtual reality scenarios which incorporate multimedia components and access annotations,
- conducting usability testing of each scenario,
- researching the effectiveness of the virtual reality in minimizing anxiety, and
- disseminating information to assist in continuation and replication of project goals.

2. TECHNOLOGY USE AND DEVELOPMENTS

Several virtual reality technologies were considered for the project, including Virtual Reality Modeling Language (VRML) and panorama imaging software. Ultimately, QuickTime Virtual Reality, a panorama system, was chosen for the following reasons:

- use of photo-realistic scenes
- speed of production
- ease of learning by production staff
- ease of use by end users
- good integration with a Web-based environment

A Panoscan panorama camera system was used to quickly and easily capture the virtual reality environments. Digital video was also shot to better illustrate certain scenes that might prove particularly difficult or stressful to individuals with mobility impairments (e.g., entering the community recreation center’s swimming pool using a hydraulic lift, adapting a rowing machine for use by a person in a wheelchair). The video was compressed using QuickTime and integrated into the VR scenario. Other multimedia techniques were used to provide text annotation of scenes, interactive maps of the facilities, voice-over and open-captioning of video, and other information pertinent to community-based access.

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3. EFFICACY STUDY

3.1 Introduction

Research into the efficacy of virtual reality technology was conducted. This study is based on the premise that visiting new environments can be anxiety-producing, especially for individuals with disabilities that might not have knowledge about access-related issues. Therefore, the CATT project investigated if the use of a virtual tour prior to visitation of a new site would alleviate anxiety in subjects with mobility impairments. Further, it sought to determine if a facilitated virtual tour experience, one in which a therapist lead the subject through the virtual scenario, would be effective in reducing anxiety. Recreation information gain was also assessed.

3.2 Methods

3.2.1 Subjects. Thirty-six subjects with physical disabilities were recruited through advertisements in local newspapers, and through direct mailing to local hospitals, community housing facilities, non-profit agencies, and disability advocacy groups. All subjects were initially screened to ensure that they met minimum guidelines for participation in the study, which included being age 18 or older, no prior participation at the 20th Street Recreation Center, no cognitive deficits, and having a physical disability that impaired mobility. Subjects were randomly assigned to one of three groups: control group, virtual reality treatment group (VR), or the leisure education-virtual reality treatment group (LE-VR). Thirty-four subjects, 21 males and 13 females, with a mean age of 47.5 years (range = 23 to 84 years) completed the study. Disabilities of the subjects were varied and included persons with spina bifida, paraplegia, quadriplegia, cerebral palsy, brain injury, and multiple sclerosis.

3.2.2 Instruments

Self-Evaluation Questionnaire: The State-Trait Anxiety Inventory (STAI) (Spielberger, 1983) was one measure used to assess anxiety. The state anxiety scale (Form Y), used to measure a temporary condition of apprehension, tension, nervousness and worry, was completed by subjects. The scale is comprised of 20 statements with a range of 4 possible responses to each. The STAI has been used more extensively in psychological research than any other anxiety inventory (Buros, 1978). Data indicate that the state scale of the STAI has reliability coefficients above .90 for samples of working adults, students, and military recruits, with a median coefficient of .93. Additionally, it is reported that alpha reliability coefficients are typically higher for the state-anxiety scale when given under conditions of psychological stress (Spielberger, 1983, p. 14). Extensive research into the validity of the STAI has been conducted, and it is reported that the state-anxiety scale repeatedly has demonstrated sensitivity to environmental stress. Furthermore, the STAI has been shown to have excellent psychometric properties for the assessment of anxiety in elderly persons (Spielberger, 1983, p. 20).

Visual Analog Scale (VAS): Each subject was asked to perform a self-evaluation of anxiety at baseline and at the conclusion of their site tour. An 11-point Visual Analog Scale (VAS) (McCall et al, 1998; Vogelsang, 1988) was used. Lower scores (0-3) indicated greater comfort with the environment; middle scores (4-7) reflected moderate comfort, while higher scores (8-10) indicated severe discomfort.

Heart Rate (HR) Measurement: In order to assess physiological changes as a result of anxiety, heart rate data were collected. Heart rate data were recorded every 5 seconds and stored using a Polar Accurex Plus Heart Rate Monitor (Polar Electro Oy, Kempele, Finland). All HR data were downloaded from the HR monitor's wrist receiver to a computer via a Polar Interface Plus (Polar Electro Oy, Kempele, Finland). Each subject had his or her HR measured to establish (A) a baseline and again while touring (B) the 20th Street Recreation Center.

(A). Baseline

Heart rates were measured during an hour of "normal" daily activity while at home or in another "comfortable" environment chosen by the subject. An average HR was determined for this time period.

(B). 20th Street Recreation Center

While touring the 20th Street Recreation Center, the heart rate monitor was used to ascertain physiological changes due to environmental anxiety. Subjects completed 11 assigned tasks while touring the Center. The subject pressed an event marker on the HR wrist receiver while also identifying the task by talking into a voice-activated cassette recorder. This enabled the identification of a specific heart rate during a specific time interval.

Recreation Information Questionnaire (RIQ): A 12-item Recreation Information Questionnaire (RIQ) was developed to ascertain the subject's knowledge of recreation-related information, frequency of recreation center use, and community independence. Composite scores were calculated by adding correct responses for each statement.

Technology Questionnaire (TQ): A technology questionnaire assessed the subject's technology sophistication, such as their ability to utilize voice mail, e-mail, FAX machines, word processing, and search for information on the World Wide Web. This instrument was adapted from the Flashlight Project (Ehrmann and Zúñiga, 1997). Flashlight™ is comprised of various assessment tools useful in helping to answer questions about technology, and it has been subjected to content validity testing.

Demographic Data: Each subject was requested to provide demographic information that included their age, sex, ethnicity, disability, current employment status, living arrangement, health status, use of assistive devices, and methods of transportation.

3.2.3 Experimental Design. The 20th Street Recreation Center, a large multi-purpose facility operated by the City of Denver, Colorado, Department of Parks and Recreation, was created into a virtual environment that included photo-realistic panoramas of the facility, digital video of recreation equipment use, access annotations, and interactive maps of the facility. Potential subjects were initially screened to ensure meeting eligibility requirements and then were randomly assigned to either a control group (n=13), treatment group one that received virtual reality only (VR) (n=10) or treatment group two that received leisure education using the virtual reality scenario (LE-VR) (n=11). All subjects were pre-tested in their home or "comfortable" environment to determine baseline anxiety levels (i.e., Self-Evaluation Questionnaire, HR, and VAS), recreation knowledge (i.e., RIQ), technology sophistication (i.e., TQ), and demographic data.

Control group subjects independently toured the 20th Street Recreation Center, completing 11 assigned tasks such as signing up for a recreation center pass, locating specific exercise equipment, and viewing the swimming pool. During the tour, subject's HR was recorded and tour data noted on voice-activated tape recorders. At the conclusion of the tour, subjects were met by project staff to complete their post-evaluation questionnaires and paperwork for receiving a stipend for participation.

Similarly, subjects in the VR only treatment group and LE-VR treatment group followed an identical protocol for their 20th Street Recreation Center visit. However, the subjects assigned to the VR treatment group had an opportunity to view and "navigate" through the Center virtually prior to their actual on-site tour. Each VR only subject, either coming to a computer lab of the CATT project or by having staff bring a laptop computer into the subject's home, virtually toured the facility, navigating through the various rooms, examining equipment, and viewing the digital video clips. Staff had been instructed to assist subjects in using the computer only and not to provide explanation or information about the facilities.

Subjects in the leisure education-virtual reality (LE-VR) group also utilized the 20th Street Recreation Center virtual environment but had this computer tour facilitated by a certified therapeutic recreation specialist (CTRS). A leisure education program, created through a modified program planning process (Peterson & Stumbo, 2000), was used by the recreation therapist to assist LE-VR subjects in using the community facility. Content of the program included information about transportation, facility accessibility information, fees/costs for participation, equipment and adaptations available, and services provided through the Special Needs Program of Denver Parks and Recreation Department.

3.3 *Results*

The premise that anxiety may be increased for individuals with disabilities who visit new environments was supported by the VAS and HR data. The STAI showed a difference in means, but it was not statistically significant. The instruments were administered to subjects in a control group before and after independently touring the 20th Street Recreation Center (Table 1).

Table 1. *Means for Control Group (n=13)*

	Pre-Site Visitation	Post-Site Visitation
VAS p=<.05	2.25	3.66
HR p=<.05	87.92	94.23
STAI	33.63	33.83

The second premise, that use of a virtual tour prior to visitation of a new site would alleviate anxiety in subjects with mobility impairments, was not supported by the data. Subjects in the VR only group were administered three instruments, then provided the treatment of the virtual reality experience, and then measured again at the 20th Street Recreation Center location. Data indicates an increased level of discomfort, anxiety, and heart rate (Table 2). While mean HR site data was lower for this group of subjects than for similar subjects in the control group, the range was much greater.

Table 2. *Means for VR Only Treatment Group (n=10)*

	Pre-Site Visitation	Post-Site Visitation
VAS	2.5	5.1
HR	77.5	90.77
STAI	32.66	38.1

The third premise, that a facilitated virtual reality tour administered prior to visiting the 20th Street Recreation Center would reduce anxiety, was supported by data from the STAI (Table 3).

Table 3. *Means for Leisure Education-Virtual Reality Treatment Group (n=11)*

	Pre-Site Visitation	Post-Site Visitation
VAS	2.3	2.7
HR	86.18	91.77
STAI p=<.10	38.09	32.36

Additionally, the RIQ was administered to all subjects before and after site visitation. The RIQ was used to determine knowledge of recreation and related resources. Data indicate increased recreation knowledge by all groups. However, the greatest increase is evident in the LE-VR group, with the VR only treatment group also showing significant gains (Table 4).

Table 4. *Means for Recreation Information for All Groups*

	Control Grp	VR Only Grp	LE-VR Grp
Pre-Site Visitation	2.39	1.1	1.91
Post-Site Visitation	4.38	5.1	7.55
	p=<.05	p=<.05	p=<.05

The Technology Questionnaire was administered to all subjects prior to site visitation. It assessed the technology sophistication of the subjects, including their ability to use voice mail, e-mail, FAX machines, word processing, and the World Wide Web. Future data analysis will focus on relationships, if any, between the subjects' technical sophistication and anxiety on-site before and after VR treatment.

3.4 Discussion

Preliminary analyses of data suggest that (a) anxiety may increase in individuals with disabilities who visit new environments, (b) use of an unassisted virtual reality tour does not result in reduced anxiety, but does increase information gain, and (c) a facilitated virtual tour prior to site visitation does reduce anxiety and provide significant information gain. Additional data analyses will be performed to confirm these preliminary results, and qualitative research (e.g., interviews) will be undertaken to provide additional insight. Of particular interest, though, are the results from the Technology Questionnaire which suggest that technology sophistication played a role in the anxiety scores of the VR only subjects.

3.4.1 Problems and Limitations. The population measured may not be completely representative of the general population of persons with mobility impairments. Many subjects responded to newspaper advertisements, and thus may be more independent and exhibit more risk-taking behaviors than the larger population. This factor suggests that the study subjects may exhibit less anxiety than the larger population when visiting new and remote sites.

3.4.2 *Future Research.* Future research may attempt to recruit subjects with mobility impairments from rehabilitation hospitals that are involved in active rehabilitation. This population may include persons with more recent disabilities, and these persons may exhibit greater anxiety when utilizing community-based facilities.

Additionally, more analysis needs to be performed on the HR data since it is suspected that physical exertion at the site may result in increased heart rate in addition to anxiety. A second physiological measure, such as salivary cortisol, may be useful in measuring neuroendocrine responses to anxiety in a natural environment (Bandelow et al, 1997).

Finally, the production technology used for the virtual reality experience was only marginally immersive since it relied on Hypertext Markup Language (HTML) and Virtual Reality Modeling Language (VRML). Newer, more immersive and interactive technologies may be more effective in reducing anxiety. The use of these technologies needs to be explored in field-based settings. In addition, the virtual reality experiences need to be more "user friendly" and easier to use for persons without extensive technological experience.

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ICDVRAT 2000

Session V. Training Environments

Chair: Jaime Sánchez

VIRT – factory trainer project. A generic productive process to train persons with disabilities

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ABSTRACT

The production of a desktop VR package to be used by trainers and educators of mentally disabled subjects who seek employment in sheltered factories has been the goal of an EC funded project named VIRT. Three virtual training environments featuring a warehouse, a workshop and an office allow the trainees to practice with typical tasks such as the assembling and the handling of materials and goods. The virtual environments are flexible and can be easily changed to create variants of the basic tasks or to change their level of complexity. The warehouse and the workshop have been extensively tested by 20 disabled workers who had no previous exposure to VR and who worked under close supervision in two Italian sheltered factories during the late period of development. Every trainee spent 96 hours practising on the VIRT-Factory Trainer environments. This activity greatly contributed to the refinement of the product and to the collection of data concerning issues such as learning of procedures and tasks, adaptation to the interaction devices and system responses, and transfer of skills. Learning was apparent even in subjects with rather severe mental insufficiency. Initial difficulties with the interaction devices were greatly diminished after a few weeks of training in all subjects. There is also initial evidence from group analyses that transfer of skills to analogous real tasks may occur. Tutors reported an increase in motivation for work in all participants, which did not change with time. It is concluded that desktop VR training can be proposed to assist the training of mentally disabled workers and that it may produce both specific and unspecific favourable effects. The package is now being distributed to interested institutions and professionals for an additional extended assessment.

1. INTRODUCTION

The demonstration of the educational and training potentials of Virtual Reality to the employers of mentally disabled workers has been the goal of an international project funded by the Horizon - Employment Initiative EC programme and recently terminated. The project named VIRT (for Virtual Reality Training) was approved on winter 1997 by the Italian Ministry of Labour and Social Affairs and was led by CIRAH, a dynamic non-profit association based in Milan supporting initiatives for the disables who are eligible for a job application. VR teams of the Fondazione Don Gnocchi (FDG, Italy) and the University of East London (UEL, UK) participated in the VIRT consortium and were responsible for the research and development activities. National co-operatives (IL MELOGRANO and CSLS from Italy) and national associations from Spain (FEPROAMI) and France (UNAPEI) participated as testing sites providing educators and trainees and carrying out an intensive training and assessment activity. Third Dimension Ltd. (UK) produced the software.

2. AIMS AND RATIONALE

Virtual Training Environments (VTEs) can be viewed as tools to assist people in carrying out tasks by providing information and feedback, for example, as a means of executing information-support activities. Perhaps the greatest potential of VE applications for manufacturing is in the area of training, because training is a component of all of manufacturing activities (Wilson et al., 1995). The application of VEs to manufacturing activities is an emerging area but surprisingly, no products have been designed specifically for the disabled workers. This may be because the training of disabled people requires specific knowledge and lies at the interface between education and rehabilitation.

Subjects with a mental disability have limited access to the training tools based on the latest affordable technologies which, on the other hand, are becoming more and more available to non-disabled in educational, training and work places. This represents a critical issue as far as equal access to resources for both disables and their tutors are concerned and will inevitably produce discrimination if educators, trainers and employers of the disabled are denied the opportunity to participate in the development of specific applications for their workers.

2.1 Aims

1) To assess whether low-cost VR technology is suitable to develop models that will supplement and improve current training procedures for subjects whose mental impairments do not totally preclude their integration in a productive activity; 2) to make educators, trainers and sensible employers aware of the potential of VR and make them responsible for a number of critical choices concerning the development, the testing and the systematic use of the new training tool; 3) to assess in the broadest possible way the impact of VR on the disables and their working environment, 4) to verify whether any transfer of skills from VR to real job activities may occur.

2.2 Milestones

We started from an analysis of the training curriculum and work experiences currently offered to employable mental disables in the participating countries. It emerged that the variety of working experiences they are exposed to is insufficient to make the trainees aware of their role in a productive process and, more broadly, in a working organisation. We concluded that a flexible tool to simulate a wider range of working tasks than those available would have a precise role in the training curriculum of disables. We anticipated it would have served to broaden their working experience, to foster their decisional autonomy, and to be more aware of their skills. More specifically, it would have been an additional way to interact with tutors and workmates, to share experiences with them, to get reliable feedback, to learn difficult attitudes such as self-monitoring and self-correction through exercise by trial-and-error, free of personal and material risks. This basic philosophy has already inspired other valuable educational applications devoted to increase independent life skills of the disables (Brown et al., 1997). We then drafted and discussed possible VR scenarios and the tasks to be simulated. Because of the variety of the manufacturing activities carried out in the participating co-operatives and the need to produce a universally acceptable training tool, it was decided to simulate a generic productive process and to split it into 3 independent modules depicting a warehouse, a workshop and an office according to the topological specificity of most training and working sites. The training has been organised around principal tasks and their variants within each VTE. A special effort has been made to provide the product with the wider possible capability to personalise the training, to mimic real job training and insure that the nature of the relationship between the trainer and the trainee be maintained. For example, it was decided to combine video clips to the VR scenarios to provide additional access to instructions and to examples of real tasks sequences, and also to ease the translation of text outputs. It was finally decided to implement the product under a widely available VR platform to maximise its diffusion, and an experienced developer was appointed. A rather intensive iterative developing-testing and refining process started in late autumn 1998 which involved the R&D teams. Deliverables suitable for extended testing have been available since early summer 1999.

A substantial effort has been also devoted to the formal training of the tutors selected by the employers among professional educators, workers and volunteers with previous experience with mentally impaired subjects. A 36 hours intensive course has been organised at FDG spanning all relevant aspects of VR technology devoted to training and education, and to all aspects of the project. Specifically, the tutors were taught how to handle the system components and how to configure the VTEs. The system response to interaction has been the subject of discussion, as it was felt that standard options such as Superscape standard navigation bars were not adequate to meet the users' cognitive and visuomotor abilities. It was then discussed how to organise the intensive training with VR and how to merge it with the trainees' daily activities at workplace. The trainers' role was to configure each VTE and select the appropriate training schedule and methodology to make the trainees' approach to VR as smooth as possible. Tutors' responsibility was also to take notes and write summary reports at the end of each session and training period.

Two complete multimedia workstations based on Pentium II 400 MHz processors were delivered at each participant site in early summer 1999. An advanced version of software was installed and the system was then introduced to the trainees and their workmates. Desktop VR demos were used for an average of two weeks to practice with the interaction devices.

3. METHODS

3.1 Participants

A group of 30 disabled workers (20 in the Italian and 10 in the French and Spanish training sites), participated in the project. All participants had learning disabilities, and matched local criteria for employability in sheltered factories. The training phase spanned an 8 months period between June 1999 and February 2000 in the Italian sites and about one month in the other two sites. Eight senior tutors recruited among staff members (3 in each of the two Italian training sites and one in each of the remaining two European sites) volunteered for the study. Each Italian tutor spent an average of 450 hours teaching VR to trainees, preparing the daily sessions, data recording and managing all sorts of problems in close collaboration with the R&D teams.

3.2 Product development

The 3 VTEs were developed one after the other and submitted to an iterative test-and-refine procedure before they were sent out to serve as experimental training tools. The contribution of the two Italian sites was essential to bring the products at the actual level of development. They worked on a total of 7 successive releases of the software, while the other European testing sites worked mainly on the final release. The VIRT-Factory Trainer package was developed under the latest Superscape VRT 5.6 for Windows. Disables interacted with the VTEs by means of a 2 button mouse (to select objects) and a 2-axis standard joystick (to navigate the VTEs). Specific "dlls" were written to improve the calibration and adapt the response of the joystick to the disables' limits and automatic zooming options were implemented to ease their approach to the smaller virtual objects. Instructions were given orally by the trainers, but textual hints were also optionally available to help on the more complex tasks.

3.2.1 Warehouse. This VTE is organised around two "poles of attraction": a set of shelves and a weighing platform located at opposite sites of a large room, which includes other active objects such as a trolley and a conveyor belt. The Warehouse was intended as the entry-level application to acquaint users with the interaction devices and system responses. It requires users to understand simple instructions such as "pick up all the large green boxes on the shelves and put them on the trolley", explore the environment, select objects by clicking on them and, sometimes, move them from one location to another. A number of conditional requirements can be introduced to make the tasks more complex. For example, the selection of objects stocked in the warehouse can be made contingent on several features, such as the colour, shape and size of the envelopes, the position of the boxes on the shelves and their weight - which may be directly checked on the weighting platform. Variants of a given task can be produced by changing features at any session to prevent the user getting bored if asked to repeat the same basic activity many times. The system can be set to provide auditory feedback for any errors, to store time taken, number of hits and failures, specifics of the task carried out, and to track any moves made inside the VE. Time limits can be also introduced.

3.2.2 Workshop. This VTE is also organised around two "attraction poles" at the opposite sites of a large room to force navigation back and forth. The workbench, where most of the activity takes place, faces a "painting oven" and an incoming conveyor belt. The application is designed to simulate the assembly of a torch starting from its basic components. Some of them must be processed and refined (e.g. painted, cut or soldered) before they can actually be used, others need to be checked because they can be faulty (e.g. batteries), others are ready to be assembled (e.g. a lens). The user must ensure that all the materials needed are available at the beginning of the job; if not, he/she must retrieve them from containers located on the workbench or from the conveyor belt. The task can be as simple as checking the charge of the batteries or as complex as carrying out the whole assembly involving up to 39 different actions to be performed in the right sequence. The final product is a torch that lights up when the switch is clicked on. As opposed to the warehouse tasks, there is no immediate feedback for errors, but textual hints can be activated to remind the user what has been done and what must be done next. This was decided in order to mimic as closely as possible what happens in real conditions, where assembling goods are practised under a tutor's supervision and errors may be only be detected when a functional check is performed. Time limits can be introduced.

3.2.3 Office. The last VTE will be only briefly described here as the project came to an end before it could be tested "on the field". It was meant to be the last and the cognitively more demanding among the VIRT VTEs. It includes two functional conveyor belts, incoming and outgoing parcels and a virtual computer to deal with orders of materials, printing of labels for outgoing parcels and lists of incoming goods to be stocked in the warehouse. Though icons can replace most of the text, the users must possess simple arithmetic and reading skills. As with the other modules, a configuration file allows the tutor to set levels of difficulty and to introduce time limits for the training sessions.

3.3 Training procedures

Every trainee in the Italian testing sites spent a total of 96 hours working on the VTEs. The activities were usually organised as daily sessions of 45 min. to 1 hour each, under close supervision. Virtual environments, tasks, pass and fail criteria were set to provide incremental levels of difficulty. Tasks in the warehouse and in the workshop comprised 13 and 12 incremental levels of difficulty, respectively, each one with several variants. The first four months of training were spent on the Warehouse VTE. Easy tasks in the warehouse were those requiring only one type of activity without time limits (e.g. selecting items on shelves according to one feature); difficult tasks were those requiring more actions with time limits (selecting, moving, weighing items according to several features). Nine of the warehouse tasks did not have time limits and four were time-limited. Levels 1 to 6 were considered easy tasks (e.g. find objects), levels 7 to 9 were intermediate (finding objects sharing several features), levels 10 to 13 were difficult. The following four months of training were spent on the WorkshopVTE. Easy tasks in the workshop required completion of only one or a few assembly steps without time limits, while the most difficult task required the completion of the entire assembly within time limits. On both VTEs, passing to a higher level was allowed after three consecutive hits. The Office VTE reached full development, but could not be tested on site before the project deadline.

Training activities were preceded by testing on a set of real tasks mimicking those in the VTEs. The same real tasks were repeated at the end of each training period (about 4 months) to assess transfer of skills.

3.4 Data recording

As we were interested in collecting information from various perspectives, we analysed the data which was automatically stored on files by the system, classified errors and tutors' interventions during the training sessions, and tried to get free reporting as possible from the trainees, their tutors, and from people not directly involved with the training itself such as parents, friends, workmates and other staff members at the work sites. Accordingly, data concerning feasibility, acceptance, side effects, impact on psychological and work-organisation factors, ways of interaction, transfer of learning, perception of usefulness and efficacy have been obtained in the form of written reports or numerical data.

4. RESULTS

4.1 The VIRT-Factory Trainer package

The main product of the VIRT project is the set of 3 virtual training environments which have passed the test-and-refine phases. The package is completed by an instruction manual, a set of configuration files to assist the training, questionnaires and rating scales for feedback information. The Italian version has been distributed to more than 60 potential user sites among those who have expressed their interest. The recipients have aggreed to use the software to train disabled workers according to the aims of the project and to provide feedback to the distributors after 6 months of utilisation.

4.2 Results of the experimental training & refinement period

This section deals with data collected from 20 trainees working in the Italian testing sites on the warehouse and workshop modules. The main characteristics of the participants are listed in Table 1. There were 2 trainees with rather severe mental retardation, no reading and counting ability, 5 trainees with intermediate mental retardation and no reading, but some counting ability, and 13 trainees with mild mental retardation who were able to read and count up to 100. Only one subject was slightly motor impaired. Subjects with severe sensory-motor deficits, epilepsy or psychosis were not included. None of the trainees had previous knowledge of standard PC applications nor was exposed to VR; four of them, however, were using simple PC videogames at home. None of the trainees dropped out of training, but the individual number of training sessions varied somewhat due to unrelated causes (some trainees had transient mild illnesses, others took a full month off in the summertime, etc.).

Table 1. *Participants' characteristics.*

Test site	Sex	Age	Handed-ness	% disability	Diagnosis *	Reading	Counting
1	F	35	Right	100	Severe mental insufficiency	No	No
1	M	23	Right	70	Mielomeningocele, mild mental insufficiency	Yes	Simple arythmetics
1	M	29	Left	75	Borderline personality, mild mental insufficiency	No	Simple arythmetics
1	F	19	Right	50	Mild mental insufficiency	Yes	Up to 100
1	F	31	Right	70	Moderate mental insufficiency	No	Up to 100
1	M	23	Right	75	Moderate mental insufficiency	Yes	Up to 100
1	F	20	Right	100	Tetraparesis, mild mental insufficiency	Yes	Simple arythmetics
1	F	28	Right	45	Hypoacusis, mild mental insufficiency	Yes	Simple arythmetics
1	M	27	Right	70	Moderate mental insufficiency	Yes	Simple arythmetics
1	M	24	Right	46	Borderline personality, mild mental insufficiency	Yes	Simple arythmetics
2	M	28	Right	100	Down's syndrome, mild mental insufficiency	Yes	Simple arythmetics
2	M	21	Right	100	X Fragile syndrome, mild mental insufficiency	Yes	Up to 100
2	M	26	Right	100	X Fragile syndrome, mild mental insufficiency	No	No
2	F	23	Right	100	Down's syndrome, mild mental insufficiency	Yes	Simple arythmetics
2	M	19	Right	100	Down's syndrome, moderate mental insufficiency	Yes	Simple arythmetics
2	M	26	Right	70	Mild mental insufficiency	Yes	Simple arythmetics
2	M	30	Left	65	Mild mental insufficiency	Yes	Up to 100
2	M	28	Right	100	Down's syndrome, moderate mental insufficiency	No	No
2	M	26	Left	100	Moderate mental insufficiency	No	No
2	M	30	Right	100	Down's syndrome, mild mental insufficiency	Yes	Simple arythmetics

* Clinical records were not always available for this project

4.2.1. Training with the virtual Warehouse. Subjects took an average of 102 training sessions (45 to 223) carrying out the warehouse tasks. The lowest training level achieved was 8 (1 trainee), the highest was 13 (14 trainees). A number of performance measures were used to document the pattern of learning, but the number of sessions to achieve a change in level seemed the most comprehensive. The group's average performance improved as a function of repetitions (time of training) and of the level of difficulty of the tasks; e.g. repetition across similar tasks improved mean performance while the change to more complex tasks produced a transient drop in performance measures, which then began to improve again with practice. For example, trainees took on average 12 sessions to change from level 4 to 5 (a time-limited task), but only 7 sessions to pass from level 7 to 8. As predicted, time-limited tasks were judged as more difficult and produced more distress to trainees than time-free tasks, in spite of the fact that time limits were set on the basis of individual performances. Two of the trainees refused to take time-limited tasks.

Summer breaks caused some trainees a transient drop of performance when they came back on training. At the beginning of the training almost all trainees reported some difficulty dealing with the interaction devices and system responses, but only 2 trainees still needed some tutor's support with navigation at the end of the fourth month. The change of performance on easy tasks documents the learning of interaction skills (Fig. 1).

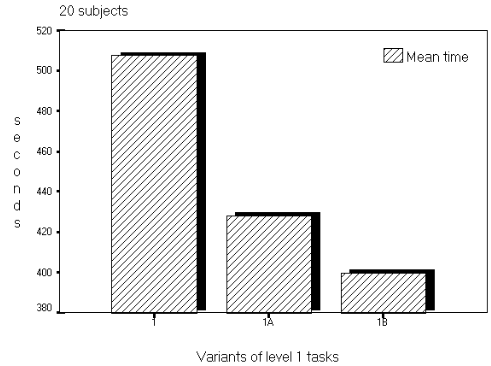

Figure 1. *Learning with the firstVTE. Total group mean time to complete variants of level 1 tasks in the virtual warehouse.*

Similarly, seven trainees reported some anxiety at the beginning, but only one still needed reassurance after four months of training. The interventions were classified into 6 types based on tutors' reports: 1, requests for a pause; 2, keeping subjects concentrated on the task; 3, minor suggestions or rehearsal of instructions; 4, assistance with navigation problems; 5, assistance with interaction problems; 6, direct solution of the problems. The majority of interventions belonged to type 4 whereas, surprisingly, very few type 1 and 2 interventions were reported (Fig. 2).

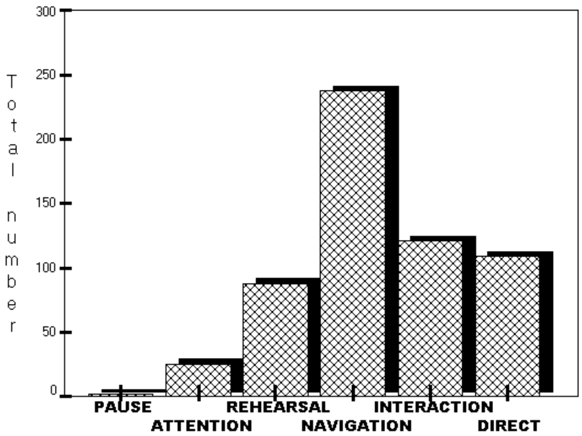

Figure 2. *Tutors' interventions during training with the first VTE.*

The correlation between a summary performance measure (based on the maximum level achieved, the number of training sessions taken and the mean time to complete a session) and clinical disability scores was significant (Spearman's r -.61; p = .004) and in the expected direction (greater disability = lower performance). However, even the more severely disabled trainees were able to show some improvement over time.

4.2.2. Transfer of learning: Warehouse tasks. This issue has been addressed to only at a preliminary level. In fact, no control groups were used and tutors served as raters, as we limited ourselves to an initial assessment of procedures to be used in future studies. The transfer of training was tested by asking subjects to retrieve items from the real warehouses according to precise indications. The tasks were repeated twice, once before and once after the training with the virtual warehouse. The number of items correctly retrieved and the time taken to complete the task were used as measures, as they may not be much affected by subjective factors. As a group, trainees were significantly faster (mean 345 ± 156 sec. vs 272 ± 236 sec.; Wilcoxon signed rank test Z= -2.11 p=.03) and retrieved more items (mean 5.6 ± 1.8 vs 6.1 ± 1.8; Z= -2.10 p= .03) after the virtual training. It must be noted that at least 4 months elapsed between the test and the retest.

4.2.3. Training with the virtual Workshop. Trainees took an average of 78 training sessions (range = 31 to 149) carrying out the workshop tasks. The lowest training level achieved was the 3rd (2 trainees), the highest was the 12th (2 trainees); the majority of the remaining subjects (n.11) could reach the 9th level. Once again, the trainees judged time-limited tasks as more difficult than time-free tasks. Unlike the warehouse tasks, time measures were not particularly useful as performance indices here, as more difficult levels also implied more activities to complete. No major difficulties with the interaction and navigation tasks were reported, as subjects were already used to them. Most of tutors'interventions were aimed to remind subjects what they should do next. In general, trainees liked the workshop environment and the assembly tasks more than the warehouse tasks. In a few cases, their motivation and performance was unexpectedly good. The linear correlation between individual summary performance measures in the two virtual learning environments was, however, statistically significant (Fig. 3).

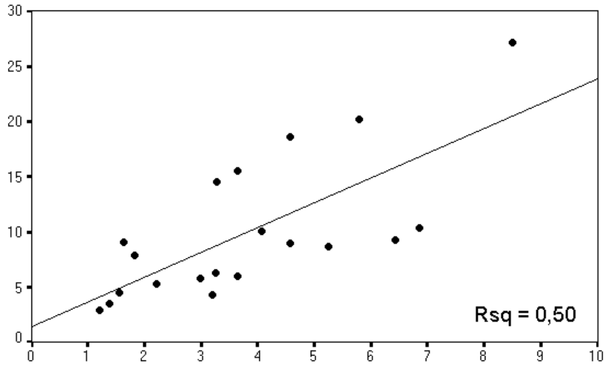

Figure 3. *Correlation between individual summary performance measures on the two VTEs. 20 subjects. VTE 1 on abscissa, VTE 2 on ordinate.*

4.2.2. Transfer of learning: assembly task. The transfer of training was tested by asking each trainee to assemble an exact real replica of the virtual torch without instructions. The test was repeated twice, once before and once after the virtual training. The number of parts correctly assembled and the time taken to complete the task were used as measures. Again, subjects were faster (mean 504 ± 251 sec. vs 439 ± 224 sec.) and put toghether more parts correctly (mean 4.5 ± 1.9 vs 4.9 ± 2.6), but the differences did not reach statistical significance. The retest outcomes were different in the two testing sites, however, as separate analyses showed a significant improvement in one and no change in the other (Fig. 4).

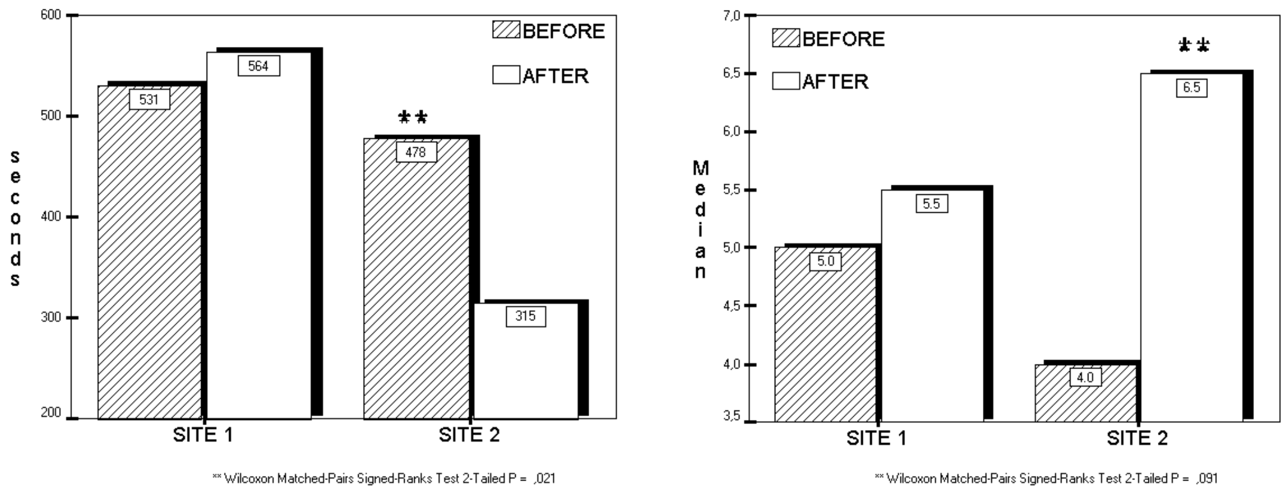

Figure 4. *Transfer of training with the second VTE. Left: mean times to complete the assembly of a real torch before and after the virtual training. Right: number of torch components correctly assembled.*

4.3 Additional results

The presence of unwanted or side-effects among participants was specifically investigated after each VR session, but no such events occurred. Tutors' notes and reports were important to interpret data stored by the system as times and number of hits and misses. Tutors reported on 92.3% of 2080 training sessions with the Warehouse and 90% of 1570 sessions with the Workshop VTEs. Overall, adequate notes were obtained 84%

of the times. Notes were critical to understand the nature of problems, difficulties and errors made by the trainees on 37.5% of failed tasks and on 11.8% of passed tasks. Non critical, but useful, notes were available on an additional 12.8% of the training sessions. Incomplete or ambiguous notes were present in 7.2 % of the cases. Tutors reported they made critical interventions on 6.5% of the sessions to solve trainees' difficulties. Technical faults occurred on 2.4% of the training sessions, but the work could be resumed within a few minutes most of the times. In their final reports, tutors stated they could not have anticipated such a significant mean improvement in their trainees' ability to work with the VTEs and - more generally - with a PC. The employers judged the impact of the VR training on workplace organisation and routines as tolerable. Most of the trainees reported enthusiastic feelings and showed high motivation which did not drop off during the training. They also showed a greater positive attitude during ordinary work tasks. Both parents and educators reported the trainees' self-esteem was improved because of the opportunity that they had to use a PC to work with. Some trainees have repeatedly shown their ability to interact with virtual learning environments during public shows and demonstrations of the VIRT-Factory Trainer package. Because of this, it was decided that disabled workers not originally included in the training would be given the same opportunity to practice with VR after the official end of the project. Following their participation to the VIRT project, some of the trainees began to use a PC at home.

5. CONCLUSIONS

The research and development activities of the VIRT project have been successfully completed within the 2-years period allocated. As a result, a set of VTEs is now available to train mentally disabled who are employed or who seek employment in sheltered factories, and to make tutors and employers aware of the potential value of VR as a new training tool. To our knowledge, this has no antecedents as far as VR applications for disabled are concerned. The VTEs embed many of the up-to-date desktop VR enhancements, run on standard hardware under Windows '95-'98 environments, are easy to configure and fully documented. Furthermore, they produce multiple outputs which may serve to document trainees' learning. The product is now being distributed at no cost to all interested parties in order to make as many professionals aware of it and to complete the expanded testing phase. The product on distribution has passed an 8 months testing-and-refinement phase in the hands of 20 disabled trainees and 6 tutors in Italy and of an additional 10 trainees in two other European countries. Feedback from the latter is expected within the next two months. This intensive activity produced a number of results, the most basic of which is that the applications are adequate for a supervised training of mentally disabled subjects who meet criteria of employability. More specifically, we have been able to document that:

- practice reduced initial anxiety levels and difficulties with standard interaction devices;
- mean performance improved during training, though time-limited tasks were perceived as more difficult and stressful;
- performance on the virtual tasks reflected to some extent the individual levels of disability and learning impairment, but even the more severely impaired subjects were able to tackle the easier tasks and learn from practice;
- motivation was not lost during repeated exposure to VR; some trainees showed transient "holidays" effects;
- there is preliminary evidence that some transfer of learning occurs from VR to analogous real tasks.

This evidence, however, is still tentative as no control groups have been used so far, and differences in tutors' attitude during training may have influenced the transfer of learning in the case of the assembly task. Results seem, nonetheless, promising enough to warrant further formal appraisal of this issue, as learning disables were already shown to able to transfer VR-trained skills into real life situations (Cobb et al., 1998).

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Virtual environments as spatial training aids for children and adults with physical disabilities

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ABSTRACT

This paper outlines experimental work on the use of virtual environments in assessing and improving spatial skills in people with physical disabilities. New evidence is presented which suggests that the degree of spatial impairment experienced by physically disabled children varies dependent on early mobility, and that this impairment may persist into the teenage years. We also review an experiment demonstrating transfer of spatial knowledge from a virtual environment to the real world, and outline a proposed follow up study examining virtual experience versus physical model experience. Finally, other studies in progress are outlined that focus on vertical spatial encoding in virtual environments based on larger real world environments and include older users as the target group.

1. INTRODUCTION

Children with physical disabilities that limit their autonomous movement in space are often unable to fully explore environments. Even those who have some form of assistance (via the use of a wheelchair, or transport by a carer) may have limited access, and may rely on their assistant to make route choices. Assistants will normally take the shortest available routes, which limits the child's opportunities for spatial choice, error correction, efficient route deduction, path integration and the other learning experiences that are probably crucial to the development of good spatial cognition in able-bodied individuals. Especially in the early stages of development, the cumulative effect of passivity and limited autonomous exploration may deprive the child of the motivation and/or ability to learn about new environments and form effective internal maps with which to navigate (Foreman et al, 1989). To date, little is known about the possible longer term effects of this early limited exploration experience when a greater degree of autonomous movement becomes available.

The few studies that have been carried out examining cognitive mapping skills have provided preliminary evidence that children with mobility limitations have difficulty forming effective cognitive spatial maps (Foreman et al, 1989; Simms, 1987). Foreman et al (1989) found that physically disabled children were worse than matched classmates at drawing plan maps of their classroom, placing missing objects on an outline map and pointing in the direction of landmarks on their school campus. Simms (1987) found that, compared with able bodied matched controls, disabled children took significantly longer to learn a route, their observation of landmarks was poorer, they were less competent at marking routes on a sketch map and produced less comprehensive hand drawn sketch maps.

Simms (1987) also found a difference in spatial skill related to level of mobility. She found that walkers performed better than those who were wheelchair bound. The following study investigated the possible persistence of limited early mobility experience in the current spatial learning ability of a group of disabled teenagers with optimal levels of mobility given their disabilities (Stanton et al, submitted, b).

2. SHORTCUT ABILITY AND EARLY CHILDHOOD MOBILITY

A group of able-bodied children and two groups of physically disabled children explored a simulated "maze" comprising four rooms linked by runways. In a subsequent test, they were asked to take shortcuts between target room locations.

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2.1 Participants

Three groups were tested: One group consisted of 24 able-bodied children with a mean age of 13.6 years. A group of 34 physically disabled children, with a mean age of 14.1 years, was divided into two sub-groups based on their history of mobility. Eleven children were rated by their teacher as more mobile when they were younger and 23 children were rated as less mobile when they were younger. All the children were assessed by their teacher as being within the normal range of intelligence.

2.2 Materials

The experimental environment was developed using the Superscape Virtual Reality Toolkit and was presented on a desktop computer. The environment consisted of five pathways connecting four rooms that appeared identical from the outside (see figure 1). The interior of each room was coloured differently and contained discriminable objects. Large distinctive landmarks were positioned around the environment as spatial cues. A series of pilot studies had established that 4 large cues were optimal for spatial orientation within this environment (see Stanton et al, submitted, b). Barriers were used to limit exploration during the learning phase.

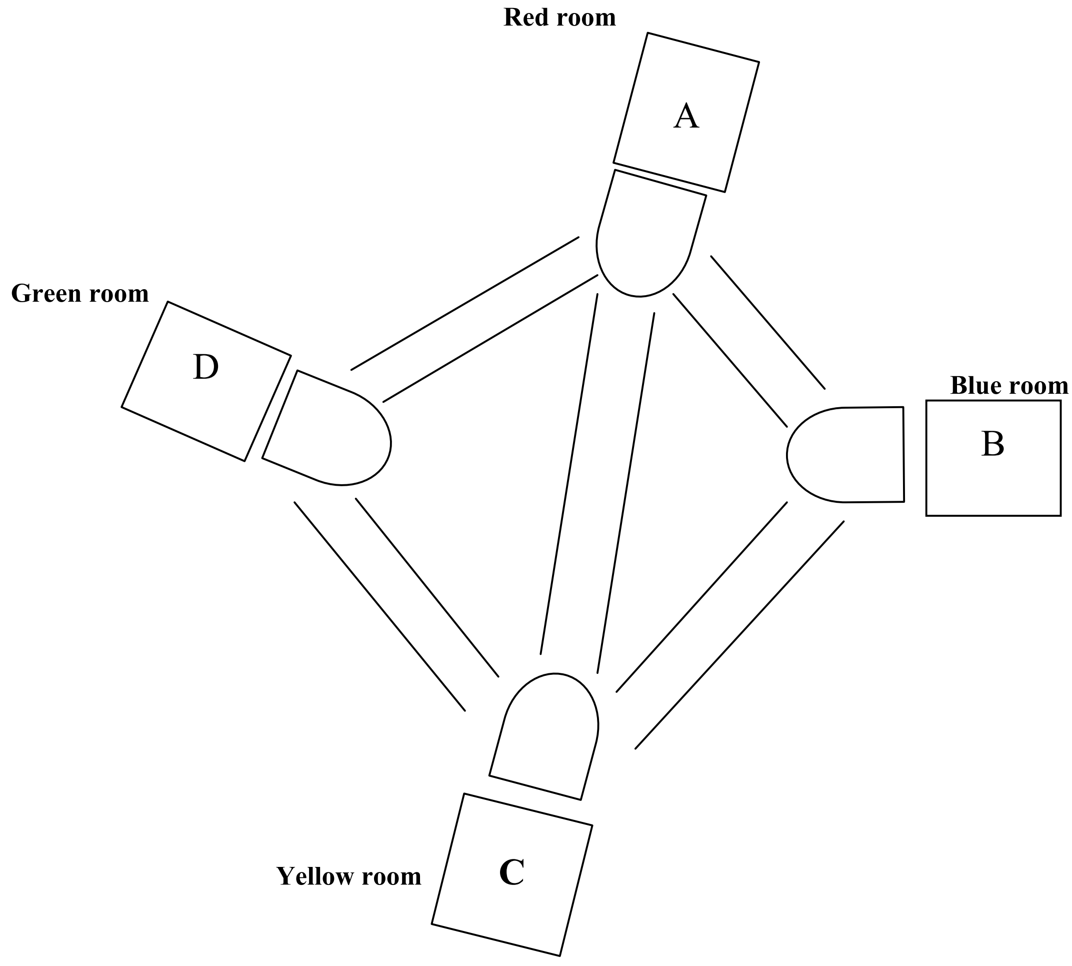

Figure 1. *Plan view of the rooms and pathways in the shortcut study environment*

2.3 Design and Procedure

In a counterbalanced arrangement participants explored three of the outer pathways on a set route determined by the experimenter. For example, they were asked to explore the route between room A and room B (all other pathways were blocked by no entry barriers). They were then asked to explore the path between rooms C and D, and then between rooms A and D. In the testing phase all the barriers were removed and participants were placed in room C and asked to find room B by the shortest route available. If they were successful on this first task they were repositioned in room C and asked to locate room A. If they had not taken the correct route the first time they were asked to locate room B again.

2.4 Results and Discussion

In the first shortcut test the probability of choosing a correct path by chance alone was 33%, while the probability was 50% on the second test. Approximately 70% of the able bodied group selected the shortcut correctly on both tests, significantly exceeding chance levels. The 'more mobile group,' while not performing better than chance on the first test (approximately 45% correct), scored better than chance on the second test with 80% correct. The 'less mobile' group only scored approximately 45% correct on both tests and therefore did not perform better than chance on either test.

This study demonstrates that disabled children are less able to take shortcuts than able-bodied children, and that those children who had had more limited mobility as young children were poorer at a shortcut task than those who were mobile when young. These results add further weight to the argument that early independent exploration is essential for the development of cognitive spatial mapping ability in children, and suggest that these early influences persist at least into the early teenage years.

3. TRANSFER OF SPATIAL SKILL FROM A VIRTUAL TO A REAL SCHOOL ENVIRONMENT

In our previous work we found that children's' ability to orientate themselves and find target landmarks in VEs improved significantly with repeated exposure to VEs of similar complexity (Stanton et al, 1996). However, the acid test for VE efficacy as a spatial training medium is whether children can make practical use of VE training in a real situation.

There are relatively few experiments that address this question of degree of transfer (for some work in this area, see Regian et al, 1992; Ruddle et al, 1997; Witmer et al, 1995). With able-bodied adult participants, Wilson et al (1997) have established that spatial knowledge (of vertical and horizontal positions of targets) in a real two-storey building can be acquired via exploration of an accurate computer-simulation.

The first study to examine transfer of virtual environment knowledge to real life training in physically disabled children was carried out by Wilson et al (1996). They asked their participants to explore a simulated building in the form of a game. Children were required to activate each of several pieces of fire equipment in the course of exploration, and to open a fire door in order to "exit" the building. The children were then asked to indicate where they thought items of fire equipment were located in the real building using a pointing device situated in a room from which the target items of equipment were not visible. They were also asked to describe routes within the building. On completion of these tasks they escorted the experimenter to the real fire equipment. The children were more accurate than a guessing control group on all the tasks, and had obviously gained a great deal of information during their exploration of the simulation.

The following study was designed to replicate the essential transfer of spatial information from a virtual to a real environment in the Wilson et al (1996) study. It also extended the former study in two ways. First, a better rendered and more complex environment was constructed, that incorporated all but the finest detail. Second, the experiment was designed to look at the effects of training on a spatial task in a virtual environment.

A to-scale three-dimensional computer simulation of a single storey real school environment was developed. Physically disabled children from a different school, who had never visited the target school, explored this simulation. They were trained to point to three objects in the environment that were not visible from the testing position. Following this training they were taken to the real school and given the same spatial tests that had been trained in the virtual school, and also some equivalent but untrained tests for comparison. As it was possible that the children could make intelligent guesses about the spatial layout of the environment in the absence of environment-specific experience, an able-bodied adult control group also completed the spatial tests within the real school. They were also unfamiliar with the test environment and had had no exposure to the virtual model (see Stanton et al, submitted a).

3.1 Participants

The participants in the experimental group were 7 physically disabled children, 6 boys and one girl. They had a mean age of 12.3 years. The control group consisted of 7 undergraduate students, 2 female and 5 male with a mean age of 25.6 years.

3.2 Materials

The primary section of Ash Field School in Leicester was created to-scale using the Superscape software. The environment consisted of an entrance door with a corridor leading into a central area and nine rooms.

The storeroom was located off the far end of the corridor. Four classrooms, a library area, a small office and the girls and boys toilets were located around the central area. All the rooms contained distinctive features.

3.3 Design and Procedure

Each child in the experimental group spent five sessions exploring the computer simulated environment. These sessions took place in their own school. During the final three sessions, when the participants stated they felt they now knew the layout of the environment they were asked to point to three target objects (which were not visible from their position) using the cross-sights on the computer screen. If their estimations were inaccurate, they were corrected. During sessions 4 and 5, after exploration of the simulation, the participant was asked to complete a route test. The experimenter positioned the child's viewpoint in a room and asked them to find a target room. Both the computer pointing task and the route test served as a training element. It was expected that participants would be better able to complete these tasks in the real school than new equivalent tests.

Experimental and control groups were subsequently taken to the real Ash Field school. Pointing accuracy was measured from two relative locations from which the children had completed computer pointing tasks in the simulation, along with a third untrained location. They were asked to estimate the direction of target objects from each of these locations using a hand operated pointing device.

Finally, each participant completed two route tests. They were taken to a room and were asked to move directly to a target room. The first route was identical to the one trained within the simulation. The second route taken was between two different rooms.

3.4 Results and Discussion

Children were more accurate than controls in pointing to landmarks that were not directly visible from three separate testing sites ($F(1,12) = 67.54$, $p < 0.01$). They not only completed the tasks previously trained in the virtual school, but they also completed spatial tests that had not been trained in the virtual environment equally well. They were able to point to objects not directly visible, and take the experimenter to places that they had visited whilst exploring, but never been formally tested on.

The most difficult task was expected to be pointing from the third untrained location, as there was a new viewpoint and new target objects to orient to. However, the experimental group were significantly more accurate in pointing than the control group from all three viewpoints, and their error scores from each viewpoint were relatively small and comparable. These results support the conclusion that the children had acquired flexible, effective internal representations of the environment from the virtual simulation, enabling them to orient themselves from a number of different positions within the real environment. Further, their way-finding ability (to adopt the shortest route between two locations) was also found to be more efficient than that of the control group (Mann-Whitney U test, $z = 2.01$, $p < 0.05$). These results add to the accumulating evidence that VE training transfers effectively to the real world and that this effect is evident even for people with physical disabilities whose spatial proficiency may be limited.

4. TRANSFER REVISITED

While this study successfully demonstrated transfer of spatial knowledge, it raised a number of points for further investigation. First, it is not necessarily the case that the unique features of virtual experience (apparent real-time movement, autonomy in directing displacements, experience of a 3-D representation) were responsible for the transfer effects. Possibly, any training that exposed participants to a depiction of the school environment would produce evidence of learning. Second, although an adult guessing control group has been used in related studies (e.g. Wilson et al, 1996), and probably represents a stringent control against which to compare the performance of disabled children, it could be argued that a control group from the same population, who do not have the same VE experience, would be preferable.

Therefore, we are following up this study, using the same school simulation, but with a much larger group of children and a more complex experimental design. In this study, a group of able-bodied children and a group of children with physical disabilities will be split into two subgroups. They will explore either (a) the original VE school simulation, and a physical model of a second school of similar complexity, or (b) a VE simulation of the second school, and a physical model of the original target school. Thus both subgroups will have VE and physical model experience, but only one group will have VE experience of the original school. As in the earlier study, all the children will then be taken for the first time to the (real) original school, and they will carry out the same spatial tasks as before. The results of this study are pending.

5. WORK IN PROGRESS

5.1 Vertical spatial encoding

The next development in our research program is to investigate the way people encode vertical as well as horizontal spatial information from exploration of virtual environments. For these studies we are using both simple multi-level experimental environments and a simulation of a complex shopping area based on a real life equivalent environment.

It may be that physically disabled children find vertical spatial encoding difficult as they are normally restricted to using lifts rather than stairs and escalators when moving between floors in a multi-level building. The lack of flow of visual stimuli could affect their orientation when moving from floor to floor. This may be a less serious problem if the lift is transparent (made of glass) and therefore one can see out of the lift while it is moving. In Wilson et al's (1996) study they found that although adults could point to objects on a different floor of the building, performance was poorer than when pointing to objects on the same floor.

While the shopping centre simulation is still in the development stage, we are using simple multi-level virtual environments to start to examine spatial encoding on the vertical plane. Participants will explore a virtual environment consisting of three floors. Each level contains a number of objects. Dependent on condition, participants will move between levels using either stairs or the lift. Following a period of exploration, participants will carry out spatial tasks which involved pointing to objects not visible from their testing position. Some of these objects will be located on the horizontal plane (the floor from which they will be tested) and others will be located on the vertical plane (on a different floor). The results from these studies are pending.

5.2 Elderly and social inclusion

We are also recruiting an elderly user group to take part in our studies. At the present time there is an emphasis on providing services to the home, for example web based shopping. Although in some cases this may prove efficient and advantageous, there is also the danger of social exclusion. By enabling elderly users to use virtual environments as a spatial navigational tool it is hoped to raise their confidence in visiting the real places, and therefore encourage social inclusion. Our elderly group will take part in spatial studies exploring virtual environments and subsequently visiting the real shopping centre.

6. CONCLUSIONS

We are accumulating evidence of the positive effect of exploration of virtual environments on spatial navigational skills. We continue to examine whether skills learned in virtual environments transfer effectively to real world environments. The challenge is not only to examine transfer from a simulation to it's real world equivalent, but also to examine more generally whether spatial skills in the real world improve after virtual environment experience. Additionally, an interesting aspect of our latest work, involving the simulated shopping centre will be to see how elderly users approach virtual environments and whether these types of environments can be integrated into the public domain.

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Virtual reality in vocational training of people with learning disabilities

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ABSTRACT

This paper reports a 3-stage investigation of virtual environments (VEs) in vocational training of people with learning disabilities. Stage 1 results showed that active interaction with a VE can give better learning than passive observation and that some of what is learned in a VE can transfer to the real world. Stage 2, a questionnaire survey, identified catering as the most popular choice for a virtual training package. Stage 3, a preliminary evaluation of that package, showed some positive transfer of training to a real kitchen test and provided clear justification for further development of this type of training.

1. INTRODUCTION

It is estimated that 2% of the population of the UK, 1.2 million people, have some degree of learning disability. This figure includes many types and severities of impairment and consequently a wide range of functional disabilities (see Jacobson and Mulick, 1996, for a review). However, even mild to moderate learning disabilities, which account for about 80% of the total, can be profoundly disruptive in terms of the educational, family, social and work lives of those affected. It is clear that for a very large number of people their learning disability is the cause of a significant level of social exclusion. It has long been recognised that one of the most effective ways to combat this problem (i.e. to increase social inclusion among people with learning disabilities) is to increase their employment opportunities. One of the keys to this, in turn, is improved vocational training.

In the UK, local authorities, private sector organisations and charities all contribute to vocational training of people with learning disabilities. Trainers employ a variety of training methods but, it is widely agreed, training is always extremely staff intensive. There is a pressing need for aids that can improve the efficiency of the training process. The potential of Virtual Reality (VR) in this regard is clear and has already been noted by others (Cromby, Standen and Brown, 1996). That VR based training can be effective is no longer in dispute (Siedel and Chatelier, 1997) and many of the characteristics of this training medium (rigorous control, instant feedback, precise performance measurement, reduced hazards, etc.) have an obvious relevance to training people with learning disabilities. VR based training packages for people with learning disabilities already exist. For example, Mowafy and Pollack (1995) described a "Train to Travel" package designed to train people with learning disabilities to use public transport. Brown and his colleagues (Brown, Neale, Cobb and Reynolds, 1999) for some years have been developing a virtual city, incorporating streets, shops and residential accommodation, for training a range of life skills. Pugnetti, Barbieri, Attree et al. (1999) have described the development of a virtual "Factory Trainer" in which people with learning disabilities can be trained to assemble a torch from prepared components, and to carry out simple labelling and packaging tasks.

All those who have reported such projects have also reported encouraging preliminary evaluations. However, such evaluations have been varied in terms of methodology and extent. It is important that the use of VR in training people with learning disabilities be fully and rigorously evaluated. For example, it is important to establish whether skills acquired by people with learning disabilities in virtual training environments transfer to real world environments. It is also important to know whether VR based training confers any advantages over more conventional training methods such as the use of video. Finally, it is important to ensure that both those with learning disabilities and their trainers feel comfortable with and have confidence in the use of this type of technology.

This paper describes our progress so far with a project commissioned by MENCAP, the UK's leading charity concerned with learning disability, to assess the feasibility of using VR in vocational training of people with learning disabilities. The project is divided into three phases.

2. LABORATORY BASED INVESTIGATION OF VIRTUAL TRAINING OF PEOPLE WITH LEARNING DISABILITIES

Two preliminary studies were performed to investigate whether it would be feasible to train people with learning disabilities in virtual environments and whether they would be likely to benefit from such training. The first study investigated whether people with learning difficulties were able to perform a task in a virtual environment, whether they enjoyed the experience, and whether they benefited from active participation compared to passive observation.

2.1. Preliminary Study 1 - Method

Participants were 30 students with learning disabilities, 16 male and 14 female, age range 17 to 46. They were all undertaking vocational training courses, 24 at Lufton Manor College, Somerset and 6 at Red House College, Colchester.

The virtual environment was constructed using Superscape VRT software, run on a desktop computer and explored using an analogue joystick. It was based on that used by Brooks et al. (1999) and depicted four inter-connected rooms in a bungalow - a bedroom, a music room, a lounge and a kitchen. In the rooms were 20 items, e.g. a piano, a bottle of wine.

Participants were allocated either to an active or a passive experimental group. Active participants were first shown how to use the joystick and were then required to find a route through the rooms in the bungalow and to search for a toy car. If a participant had trouble manipulating the joystick, a minimum level of help was provided. Passive participants were required to watch a replay of the progress of the previous active participant and to search for the toy car. The toy car was in the kitchen, the last room they entered.

Immediately they had finished the task, all participants were asked if they could remember how many rooms there had been in the virtual bungalow. They then performed a spatial recognition test in which they were required to select room shapes, exit walls, and the positions of exit and entry doorways according to their recollections of the bungalow. Their selections were assembled into 2-D plans of the spatial layout of the bungalow. There followed an object recognition test in which participants were randomly presented with colour photographs of 20 items from the bungalow and 20 distractors and were required to respond "*Yes*" or "*No*" depending on whether or not they remembered the item had been in the bungalow. After the object recognition test, the passive participants were given the opportunity to explore the bungalow themselves and 12 took advantage of this offer.

Finally, all the participants were asked the following questions: "Did you enjoy taking part in the study? Would you like to use virtual environments during your college training? Do you often use computers? Have you used a joystick before?".

In addition, all the active participants and those passive participants who had explored the VE were asked: "Were you able to use the joystick to explore the bungalow?".

All participants were then thanked for their participation and the purpose of the study was explained to them.

2.2. Preliminary Study 1 - Results

In all the statistical analyses reported in this study, the alpha level was set at 0.05. Participants in the active and passive groups did not differ in terms of age [$t(28) = 0.59$, $p = 0.56$]. Twenty-nine of the 30 participants reported that they enjoyed taking part in the study and 24 reported that they would like to use virtual environments during their college training. Active and passive participants did not appear to differ in their familiarity with computers with 12 active participants and 13 passive participants reporting that they used computers often. Neither did they differ in their prior use of a joystick with 8 active participants and 7 passive participants reporting that they had used a joystick before. With regard to using the joystick in the present study, 13 of the 15 active participants reported that they were able to use the joystick compared to 11 of the 12 passive participants.

Performance on the spatial layout recognition test was scored on a predetermined criterion, which allocated a maximum of 4 marks according to number and shapes of rooms, entry doorway positions, exit walls and exit doorway positions that participants correctly identified. This gave a total maximum score of 20 for the whole test. Object recognition was also scored out of a possible 20 points. To correct for guessing, incorrectly recognised lure objects were subtracted from correctly recognised target objects (Baddeley, et al., 1990).

Table 1. *The effects of active and passive participation in a virtual environment on subsequent spatial and object recognition.*

	Active Mean	SD	Passive Mean	SD
Spatial Recognition Test	11.07	2.66	8.13	2.53
Object Recognition Test	10.27	2.15	10.73	3.96

Table 1 shows the results of the spatial and object recognition tests. Inspection of this suggests that active participants scored higher than passive in the spatial layout recognition test but that active and passive participants' scores were similar in the object recognition test.

A 2 x 2 analysis of variance (ANOVA), with one between subjects factor, Participation (active vs. passive), and one within subjects factor, Test (spatial recognition vs. object recognition), was performed. Neither the effect of Participation [$F(1,28) = 2.15$, $p = 0.15$] nor the effect of Test [$F(1,28) = 1.94$, $p = 0.17$] was significant but there was a significant interaction between Participation and Test [$F(1,28) = 6.94$, $p = 0.01$]. An investigation of this interaction showed significant differences in the spatial recognition test between active and passive participants with the active participants scoring higher [$t(28) = 3.10$, $p = 0.004$. In the object recognition test, there was no significant difference between the active and passive participants [$t(28) = 0.40$, $p = 0.69$].

The above results therefore showed that active participation enhanced recognition of the spatial layout of the virtual bungalow compared to passive observation of the active participants' progress. Conversely, active participation did not enhance recognition of virtual objects compared to passive observation.

The second study investigated whether virtual training of a simple task would transfer to improved real task performance.

2.3. Preliminary Study 2 - Method

Sixty-five students with learning disabilities, 34 male and 31 female, age range 16-46, volunteered to participate in the study. They were all undertaking vocational training courses, 38 at Lufton Manor College, Somerset and 27 at Red House College, Colchester.

Real and virtual versions of a steadiness tester (Rose et al., 2000) were used in the study. The real steadiness tester consisted of a curved wire, 500 mm long and 2 mm wide, suspended between two 200 mm high vertical supports. Encircling the wire was an 80 mm diameter metal ring attached to a 40 mm long metal rod. At the end of the rod was a wooden handle. The participant was required to hold the handle in her/his preferred hand and move the ring along the wire from one vertical support to the other and back again, trying not to allow the ring to touch the wire. If the ring did touch the wire, a buzzer sounded and an error was recorded on an electrical counter.

The virtual version of the task was created using Superscape VRT software. A computer generated 3D simulation of the steadiness tester comprising the wire, the supports and a metal ring, was run on a desktop computer. 3D Movement of the ring along the wire was controlled using a Polhemus FastTrak sensor and receiver. The sensor was attached to a wooden handle that was identical to the handle of the real steadiness tester. As with the real steadiness tester task, the participant was required to hold the handle in her/his preferred hand and move the ring along the wire from one vertical support to the other and back again, trying not to allow the ring to touch the wire. If the ring touched the wire, a buzzer sounded.

Participants were tested individually. They sat in front of the real steadiness tester whilst the task was explained to them. They then performed one test trial on the real steadiness tester during which their performance and errors were noted. In the opinion of the experimenter, the performance of 20 of the volunteer participants was not considered to be of a sufficiently high standard to benefit from further training. These volunteers were thanked for their participation in the study and given the opportunity to perform the virtual steadiness task if they wished. The remaining 45 participants were randomly allocated to three groups - a real practice group, a virtual practice group and a no practice group.

Participants in the real practice group were then instructed to perform five practice trials on the real steadiness tester followed by a final test trial. Their performance was self-paced but they were encouraged to rest between the practice trials and before the final test trial. Participants in the virtual practice group sat in front of the virtual steadiness tester whilst the task was explained to them. They were instructed to perform five practice trials on the virtual steadiness tester followed by a final test trial on the real steadiness tester. Their performance was also self-paced and they were encouraged to rest between and after the practice trials. Participants in the no practice group chatted to the experimenter for approximately 10 minutes. This time period was based upon pilot data that showed that 10 minutes was the average time taken by participants to complete the real or virtual practice trials. They were then instructed to perform a second test trial on the real steadiness tester.

At the end of the study, participants were thanked for taking part and the purpose of the study was explained to them. Participants in the real practice and no practice groups were also given the opportunity to perform the virtual steadiness tester task and approximately half of them took advantage of this offer.

2.4. Preliminary Study 2 - Results

In all the statistical analyses reported in this study, the alpha level was set at 0.05. Table 2 shows participants' errors as a function of test and practice.

Table 2. *Participants' errors as a function of Test and Practice.*

	First Test		Final Test		% Improvement	
	Mean	SD	Mean	SD	Mean	SD
Real Practice	68.53	22.47	42.40	18.25	36.10	20.65
Virtual Practice	66.27	17.09	50.67	17.33	23.13	17.26
No Practice	67.53	30.39	60.20	21.80	6.58	18.65

It appears from Table 2 that improvement across trials in the real and virtual practice conditions was higher than improvement in the no practice condition. In support of this interpretation of the data, an analysis of variance (ANOVA) performed on percentage improvement scores with one between-subjects factor, Practice (real vs. virtual vs. no practice), showed a significant effect of Practice [$F(2,42) = 9.19$, $p < 0.001$]. An investigation of this significant effect showed a significant difference between real and no practice [$t(28) = 4.11$, $p < 0.001$] and between virtual and no practice [$t(28) = 2.54$, $p = 0.02$] with a marginally significant difference between real and virtual practice [$t(28) = 1.87$, $p = 0.07$]. It therefore appears that real and virtual practice both resulted in better real task performance than no practice but that real practice was marginally more beneficial than virtual practice on subsequent real task performance.

3. QUESTIONNAIRE SURVEY AND SMALL GROUP FOLLOW-UP OF LEARNING DISABILITY TRAINERS TO INVESTIGATE THEIR VIEWS OF USING VR WITHIN VOCATIONAL TRAINING

Questionnaires were distributed to trainers at MENCAP's three colleges and to MENCAP Pathway Employment trainers throughout the country. Forty-nine completed questionnaires were received. The reported number of people with learning disabilities trained each year ranged from 3 - 60, depending whether trainers worked alone or in a college setting. Trainers were presented with a comprehensive series of questions relating to their trainees and their training methods followed by a number of possible responses and space for additional responses. They were required to tick any responses that applied to them and to rank their responses in order of importance. For example, to the question "How are your trainees referred to you?", the most ticked and most highly rated response was "by the Social Services".

The training most frequently undertaken by these trainers was Vocation Specific, followed by Health and Safety, Personal Development and Social Skills. With regard to vocation specific training, the most frequently cited vocation was Catering, followed by Horticulture, Factory Work and Retail. The most frequent vocational qualification undertaken by people with learning disabilities was the National Vocational Qualification (NVQ) Level 1 with 67 students per annum taking Catering and 43 taking Horticulture.

Training methods included demonstration, systematic instruction and task analysis and these were all considered to be time consuming aspects of the training process. Another time-consuming aspect was the preparation of suitable training material. The most common training aids were workbooks and videotapes.

The biggest barriers to learning were judged to be lack of confidence, memory difficulties and attention problems.

On the basis of the responses in these questionnaires, it was decided that a virtual kitchen with tasks based on NVQ Level 1 Catering would be the most useful virtual environment with which to assess the feasibility of using VR in vocational training of people with learning disabilities. The virtual kitchen was modelled on a real kitchen used by NVQ Level 1 Catering students at Red House, Colchester.

The responses of eight trainers to the tasks contained in the virtual kitchen were sought on a follow-up questionnaire. There were three main suggestions that emerged from these questionnaires. One was to include a video facility depicting real task performance that could be operated by students if they wished. Another was that the voiceover should be slower with a repeat facility. The third was that there should be the facility to break down tasks into smaller steps that could be gradually increased to encompass the whole task. These suggestions were all incorporated into the final version of the virtual kitchen.

4. A PRELIMINARY EVALUATION OF A VR BASED PROGRAMME FOR CATERING TRAINING FOR PEOPLE WITH LEARNING DISABILITIES LEADING TO THE NATIONAL VOCATIONAL QUALIFICATION AT LEVEL 1

Real task performance before and after virtual kitchen training, real kitchen training, workbook training and no training were compared in this preliminary evaluation.

4.1. Method

Twelve students with learning disabilities, 6 male and 6 female, age range 15 - 33, volunteered to participate in the study. They were all undertaking catering courses, six at Harlow College, Essex, and six at Pinewood School, Ware.

The virtual kitchen was constructed using Superscape VRT software, run on a desktop computer, explored using the keyboard direction arrows, and manipulated using a mouse. There were four food preparation and cooking tasks - meat (pork chops), fish (salmon steaks), vegetables (carrots), and fruit (apples). A further task involved recognising potential hazards that were distributed around the virtual kitchen. Twelve hazards were presented in four sets of three.

All participants were tested and trained individually. They were first pre-tested on all four food preparation tasks in the real kitchen. For each task they were marked out of 20 points on 10 items, e.g. washing hands in the correct sink, choosing the correctly coloured chopping board. They were also asked to identify any potential hazards they could find in the real kitchen and their performance was marked. (Twelve potential hazards were distributed around the kitchen, e.g. a toaster with a frayed flex, a puddle on the floor).

They were then trained, for approximately 15 minutes each, on three of the food preparation tasks, one in the real kitchen, one in the virtual kitchen, and one in specially designed workbooks. They were also trained to identify three of the hazards in the real kitchen, three in the virtual kitchen, and three in their workbooks. They did not receive any training on one food preparation task and three hazards. The tasks and hazards were fully counterbalanced across participants so that equal numbers of participants were trained on each of the tasks and hazards in the different mediums. Participants all received three training sessions over a two or three week period. They were then re-tested in the real kitchen on all four food preparation tasks and all the hazards using the same criteria as had been used previously.

4.2.Results

In all the statistical analyses reported in this study, the alpha level was set at 0.05. Scores in the food preparation tasks as a function of type of training are shown in Table 3.

Table 3. *Pre-test, post-test and improvement scores in the food preparation tasks as a function of type of training.*

	Real Training		Virtual Training		Workbook Training		No Training	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Pre-Test	6.00	2.83	6.41	2.39	5.91	2.11	5.83	2.29
Post-Test	12.00	2.26	14.75	4.07	9.58	2.39	8.67	3.26
Improvement	6.00	3.36	8.33	4.89	3.67	2.87	2.83	3.59

It appears from Table 3 that improvement from pre to post-test in the real and virtual training conditions was higher than improvement in the workbook and no training conditions. An ANOVA performed on improvement scores (calculated by subtracting pre-test scores from post-test scores) showed a significant difference between the four training conditions [F(3,33) = 7.03, p = 0.001]. Subsequent analyses showed significant differences between virtual and workbook training [F(1,11) = 7.71, p = 0.018] and between virtual and no training [F(1,11) = 10.27, p = 0.008] with virtual training showing more improvement in each case. There was no significant difference between real training and virtual training [F(1,11) = 2.64, p = 0.13].

Scores in the hazard recognition task as a function of type of training are shown in Table 4.

Table 4. *Pre-test, post-test and improvement scores in the hazard recognition task as a function of type of training.*

	Real Training		Virtual Training		Workbook Training		No Training	
	Mean	SD	Mean	SD	Mean	SD	Mean	SD
Pre-Test	1.33	0.49	1.00	0.85	1.33	0.78	1.58	0.90
Post-Test	2.67	0.49	2.42	0.90	2.33	0.78	2.00	0.85
Improvement	1.33	0.65	1.42	1.08	1.00	0.95	0.42	1.17

An ANOVA performed on improvement scores showed a significant difference between the three training conditions [F(3,33) = 3.32, p = 0.32]. Subsequent analyses showed a significant difference between virtual and no training [F(1,11) = 16.5, p = 0.002] but no significant difference between virtual and workbook training [F(1,11) = 1.36, p = 0.27] nor between real and virtual training [F(1,11) = 0.05, p = 0.82].

It therefore appears that participants benefited more from virtual training than from workbook training in the food preparation tasks but this benefit was not apparent in the hazard recognition task.

5. DISCUSSION

The laboratory based part of the present research programme provides empirical evidence that, for people with learning disabilities, active interactions with an environment can produce better learning of at least some types of information than passive observations of that environment. This suggests that the use of virtual representations of training situations should be a valuable addition to the conventional use of video recordings, especially as the majority of participants reported that they enjoyed interacting with the virtual environment. The laboratory based studies also show that what is learned in a virtual environment can transfer to a real world test situation. Whilst these findings have been reported before with regard to other populations (Brooks et al, 1999; Rose et al, 1999; 2000), confirmation of their validity with people with learning disabilities is a crucial step in assessing the feasibility of using VR in vocational training of this group.

When taken out of the laboratory and applied to real world vocational training in catering there is also evidence of significantly better transfer from virtual training to the real task than from the conventional workbook training method. However, on other aspects of the training (hazard spotting) virtual training was no better than work book based training in terms of its contribution to final real world performance. This variation between different aspects of the training requires further investigation. As yet only 12 students have been included in the evaluation of the virtual catering training and a clearer picture of benefit may emerge when this number is increased.

There are also further questions to address. Nowhere in our results is there any evidence that virtual training is actually superior to real training. Its advantage to trainers, therefore, will lie in its potentially being more efficient and, in particular, less demanding of staff time. We intend that this will be further investigated within a more extensive trial of the virtual catering package in a number of training centres.

A further potential advantage of VR in vocational training for people with learning disabilities lies in its adaptability to individual profiles of ability. As noted above the population we are here concerned with includes a wide range of types and severities of learning disability. This necessarily complicates the task of trainers. However, the virtual kitchen, with its comprehensive performance monitoring facility, can be used to assess individual students before training begins and thus allow the trainer to more precisely tailor the training programme to the individual student. A closer examination of this will also form part of the remainder of the present evaluation.

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Effective strategies of tutors teaching adults with learning disabilities to use virtual environments

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ABSTRACT

Nine adults with learning disabilities spent up to twelve sessions with a non-disabled tutor learning to use desktop virtual environments designed to teach independent living skills. Sessions were recorded on videotape and analysed for frequency of tutor behaviours and goals achieved by learners. Before goals could be achieved, the learner had first to master the interaction devices and then learn to navigate around the environment. Preliminary analysis suggests that goal achievement maintains a constant level while instruction about the input devices and specific information about the environment decrease. Behaviours that maintain attention and motivation increase while positive feedback remains constantly high.

1. INTRODUCTION

Following an increase in its role in mainstream education, computer delivered instruction has started to make a contribution to the education of children with learning disabilities (Goldenberg 1979; Dube, Moniz & Gomes 1995; Chen & Bernard-Opitz, 1993). Interactive software encourages active involvement in learning and gives the user the experience of control over the learning process (Pantelidis, 1993). This is especially important for people with learning disabilities who have a tendency to passive behaviour (Sims, 1994). The learner can work at their own pace (Hawkridge and Vincent, 1992). They can make as many mistakes as they like without irritating others and the computer will not tire of the learner attempting the same task over and over again, nor get impatient because they are slow or engrossed in particular details (Salem-Darrow, 1995).

As an example of interactive software, virtual environments have a contribution to make to the education and training of students with learning disabilities (Cromby, Standen and Brown, 1996). Cromby et al (1996) draw attention to three characteristics in addition to those shared with other forms of computer delivered education which make them particularly appropriate for people with learning disabilities. First, virtual environments create the opportunity for people with learning disabilities to learn by making mistakes but without suffering the real humiliating or dangerous consequences of their errors. Secondly, virtual worlds can be manipulated in ways the real world cannot be. A simple world can be constructed within which the task could be performed and as the user becomes more familiar with the task the world can become more complex. Features to which the learner needs to pay attention can be made more prominent (McLellan, 1991).

Thirdly, in virtual environments rules and abstract concepts can be conveyed without the use of language or other symbol systems. Virtual environments have their own "natural semantics" (Bricken, 1991): the qualities of objects can be discovered by direct interaction with them. They can thus be used to facilitate concept attainment through practical activity, by-passing the need for disembedded thinking (Donaldson, 1978) which people with learning disabilities often find difficult to acquire and use.

Initial work suggests that virtual environments are effective in facilitating the acquisition of living skills for example shopping and navigating new environments (Standen, Cromby & Brown, 1997, 1998; Standen and Cromby, 1997) and Makaton sign language (Standen and Low, 1996) by children with severe learning disabilities. With the wider availability of computers in both primary and secondary schools for mainstream and special education (Light, 1997) there is a need to investigate a range of questions about this new aid to learning. However at the same time, there are adults with learning disabilities who may have had little or no computer experience at school but whose continuing educational needs have been recognised by the Tomlinson Report (1997).

Around 20 people in every thousand have mild or moderate learning disabilities and about three or four per thousand have severe learning disabilities. They are unlikely to enter employment when they leave school or to achieve the level of independence expected by the rest of society. Adults with learning disabilities will have the option to attend some form of college or day centre, the role of which is to provide training programmes relating to the development of daily living, social and educational skills. As in special education, VE have a role to play in this. Brown et al (1999) have developed a virtual city for people with learning disabilities to facilitate the learning of skills like catching a bus, road crossing and buying food in a café

Rostron and Sewell (1984) see computers as just "one more useful facility in the general remedial framework that is available" (p9) but advise that they are not there to replace human teachers, just to provide them with additional teaching aids. Computers are highly motivating but Rutkowska and Crook (1987) caution against the naïve belief that unguided interaction can effectively exploit their educational potential (p91). There are two ways that interaction can be guided in this form of learning. The first is through the involvement of a human tutor. The work described above using virtual environments was carried out utilising desk top systems where the public nature of the display allows interactions between the learner and a tutor. A study by Standen & Low (1996) examined the strategies employed by teachers who were encouraging school aged students with severe learning difficulties to use a virtual environment to learn Makaton sign language. They found that teachers contributed significantly less as sessions progressed selectively dropping the more didactic and controlling behaviours in their repertoire.

For both children and adults with learning disabilities it is important to learn with a tutor but staff are responsible for too many students to be able to give one-to-one tuition on a regular basis and when they are able to provide this function need guidance on effective strategies. According to Hawkridge and Vincent (1992) teachers need help and encouragement to build their confidence and skills in using computers and deserve proper training opportunities. Resolution of this situation involves a consideration of the functions of the tutor. One of the primary functions of tutoring according to Wood, Bruner and Ross (1976) is to allow the learner to make progress by initially providing scaffolding, for example by controlling those elements of the task that are initially beyond the beginner's capability. As the beginner becomes more familiar with elements of the task and develops the ability to carry it out independently the tutor intervenes less. Another is to maintain the learner's interest and motivation, marking relevant features of the task and interpreting discrepancies between the learner's productions and correct solutions. As proposed by Slator et al (1999) the first of these functions could be incorporated into the software. This would be either in the form of unintrusive tutoring (giving advice but not preventing actions) or intelligent software tutoring (providing feedback based on the tutoring agent's experience of the task and the learner's behaviour). Such a software tutor would enable a less experienced person, even a peer to carry out the function of maintaining the learner's interest and motivation.

In order to inform the design of the software tutor we set out to investigate what strategies human tutors used when working with adults who were learning to use virtual environments and how effective these strategies were.

2. METHOD

2.1 Participants

So far data are available on 9 people attending a social services adult training centre for people with learning disabilities. They would all be described as having moderate to severe learning disabilities but staff have yet to score them on the AAMR Adaptive Behaviour Scale (Nihira et al 1998).

2.2 Design

Each participant completes up to 12 sessions and changes from baseline and over time are examined

2.3 Virtual environments

The virtual environments shown in Figure 1 have been developed as part of the Virtual City project sponsored by the National Lottery Charities Board. The project consortium consisted of The University of Nottingham, The Shepherd School and The Metropolitan Housing Trust (Brown et al, 1999). All of these environments were displayed on Pentium II with 17" monitor, operated using a standard 3 button mouse or trackball.

2.4 Procedure

Service users who wished to take part spent a session using a 2 dimensional routine to learn how to use the mouse. Once this had been mastered they moved on to the other environments in the same order (road crossing, café, supermarket, factory) only progressing to the next once a defined level of mastery had been achieved. Sessions were scheduled as close as possible to twice a week and lasted approximately 30 minutes. They were recorded on videotape, the camera positioned to view both the learner and the tutor sitting next to them.

Virtual Supermarket

The Virtual Supermarket was based on a real supermarket in Nottingham and aimed to promote basic shopping skills. The Virtual Supermarket is illustrated here and the learning objectives identified for this environment are as follows:

- Creating an icon-based shopping list
- Selecting items from the shelves
- Finding all the items from the shopping list
- Paying for goods at the checkout

Virtual Café

The contents and layout of the virtual café were based upon the University of Nottingham's Art Centre Café. The Virtual Café is illustrated here and the learning objectives identified for this environment are as follows:

- Making choices and decisions – ordering drinks from a list for self and others.
- Social skills when ordering
- Communication with staff and public
- Money handling - paying for drinks
- Appropriate behaviour - table manners, etiquette
- Appropriate dress
- Toilet use in public situation
- Dealing with alcohol - what drinks you can order at what ages, and the affects these drinks may have on you

Virtual Transport

The Virtual Transport system was designed as a way of physically linking the other three VEs. Thus, the user could take the bus from the house to the supermarket, or to the café, etc. The bus route was not modelled on any actual location but the buses themselves were made to resemble Nottingham City buses which the users would be using. The Virtual Transport environment is illustrated here and learning objectives identified for this VE are as follows:

- Select the correct coins for the bus
- Leave the house with enough time to catch the bus
- Cross the road safely
- Catch the correct bus
- Pay the bus driver and collect your ticket
- Get off the bus at the correct stop

Virtual Factory

The Virtual Factory was designed in collaboration with the Health Authority to teach health and safety skills to people with learning disabilities entering sheltered employment. The learning objectives identified for this VE are:

- Selecting correct clothing before entering the factory
- The dangers of entering black and yellow lines
- Storage of chemicals
- Fire safety drills
- Collection of COSSH forms
- Hygiene within the factory

Figure 1. *Virtual Environments.*

3. RESULTS

3.1 Coding of videotapes

The coding system was developed with the help of RB who had previously carried out a pilot study on 9 service users. The system went through 3 different phases before a satisfactory level of repeat reliability (between 75 and 80%) could be established.

Tutor behaviour was coded into 5 categories

- *Specific information* given to learner about achieving a goal and was further categorised as being about the mouse, the joystick or the environment (e.g. "go over to the bar now).
- *Non-specific information* did not provide the help a learner needed to achieve a goal but made the learner aware of possibilities and was similarly categorised as concerning the mouse (e.g. "where are you going to click then?"), the joystick or the environment.
- *Gesture* covered any movement made by the tutor for example pointing to direct attention to the screen or to instruct movement of the arrow on the screen or to direct movement through the environment.
- *Touching* controls included the tutor putting their hand over the learner's or taking over the input device to demonstrate and was further categorised as concerning either the mouse or the joystick.
- *Feedback* could be either positive such as praise or reassurance (e.g. "well done", "that's good") or negative ("no, not like that").

Learner behaviour was categorised in terms of the number of goals they achieved in an environment and could be either positive (finding an item on the shopping list) or negative (stepping into the road before the light has turned to green).

3.2 Analysis

Sessions were divided into 10 second intervals and whether or not a particular behaviour started during this interval gave it a score of 1. Therefore the maximum score for a behaviour for any one session could not be greater than the number of 10 seond intervals in that session. The score was converted to rate per minute to take account of differences in duration of sessions.

3.3 Use of input devices

One of the tasks of the tutor was to assist with mastery of the input devices but specific information about them was always given at a lower rate than about the environment itself. Both touching and specific information about the mouse (see Fig. 1) and the joystick (see Fig. 2) did decrease over repeated sessions. Unsurprisingly there were very low levels of non-specific information throughout.

3.4 Learners' achievement of goals

Environments differed in the number of goals there were to achieve and on the early attempts at each environment not all goals were attempted. Figure 3 shows the rate per minute at which goals were achieved irrespective of which environment the learner was working on. To give context to the activity of the tutor, it appears that learners were achieving goals at a steady rate. However, to give a true picture of achievement, rates need to be adjusted to take account of the total possible number of goals that could be achieved in each particular environment and also whether the learner had just progressed to that environment.

3.5 Tutors' strategies

Although learners' goal achievement was remaining at a steady level, tutors provided less and less specific information as sessions progressed while giving increasingly more non-specific information (see Fig. 4). Negative feedback was always very low while positive feedback remained at a high level. Closer analysis might illustrate whether this was needed to maintain learners' motivation or because it was a default level for the tutor and insensitive to behaviour on the part of the learner.

4. DISCUSSION

Although we had established a method of coding in an earlier study a new scheme had to be adopted for this study because the participants were much more able and verbal. However, this new system retained the distinction between help with input devices and help with negotiating the environment. The amount of help given with the mouse was much lower than that given with the joystick because specific training was given with the mouse prior to starting on the first virtual environment. Similar training with the joystick would have been helpful as well as a user friendly method for determining individual settings for the controls. The distinction between specific and non-specific information follows work on children's learning (Wood et al, 1976) where different levels of control exerted by the tutor were distinguished. Changes over time in the present study suggest that this distinction is worth maintaining. The tutors appear to be following the expected pattern of intervening or controlling less thus allowing more time for the behaviours which maintain the learner's interest and motivation and function to interpret the learner's activity. This distinction might also correspond to that between tasks which can be written into the software tutor (specific information) and those that need the presence of a human tutor. Although preliminary analysis of data shows interesting changes over time, the true value of the effectiveness of the strategies can only be determined by further, closer analysis.

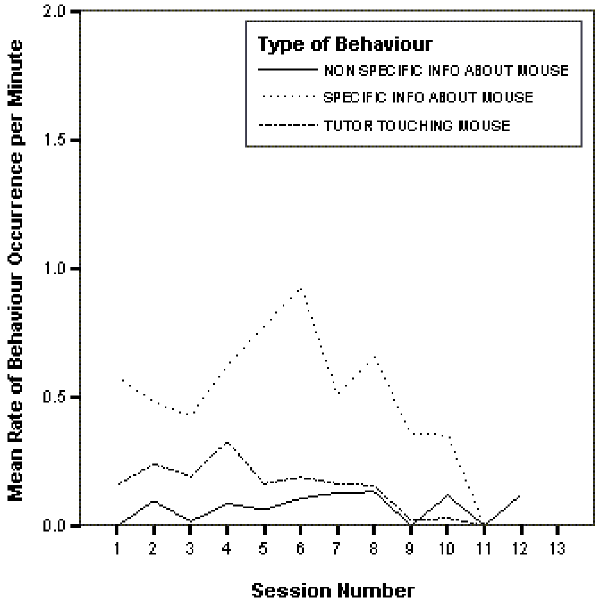

Figure 1. *Tutor behaviours relating to mouse.*

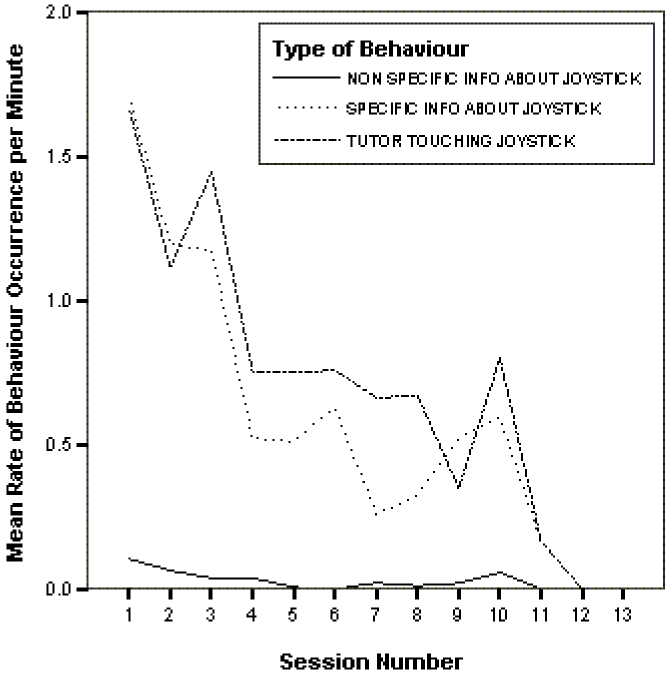

Figure 2. *Tutor behaviours relating to joystick.*

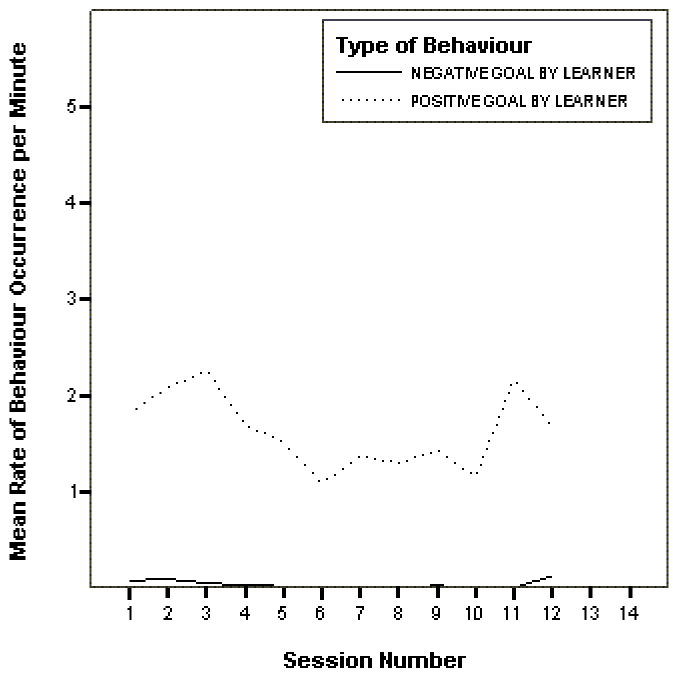

Figure 3. *Goals achieved by learner.*

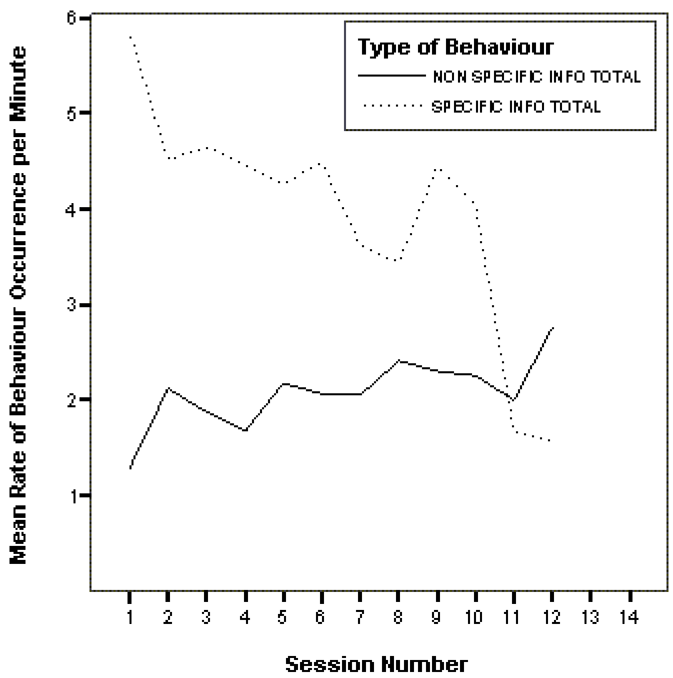

Figure 4. *Type of information given by tutor.*

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ICDVRAT 2000

Session VI. Virtual Environments & Autism

Chair: Elizabeth Attree

Employing virtual reality for aiding the organisation of autistic children behaviour in everyday tasks

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ABSTRACT

This paper documents part of a research project under the title: "Computer-Assisted Education and Communication of Individuals with Autistic Syndrome", which aims at designing and developing computer-based environments for aiding the education and assessment of autistic children. The theoretical basis of the project is explained. Finally, a scenario titled "Returning Home" for a virtual reality application, which would aid educators in organising the behaviour of autistic children in a series of everyday activities, is described.

1. INTRODUCTION

It is widely accepted that autistic children perceive the world and human behaviour in a unique manner. Autistic perception is governed by an idiosyncratic way of processing information. Most therapies and educative methods aim at being more effective by adjusting and meeting the specific needs of "autistic" understanding. Some of these needs make the use of virtual reality technology more relevant to the education of autistics.

One of the hypotheses about the phenomenology of the autistic syndrome is that autism derives from a lack of coherence in the processing of new information (Frith, 1989). The main difficulty of autistics is in understanding higher human mental activities, like expression of emotions, motives, beliefs and intentions, ultimately resulting in disabling communication. Therefore, the lack of coherence and the fragmented perception of autistics could justify characterising the world conceived by them as "*virtual*". In this sense, it could be hypothesised that if we present autistic children with a *"virtual"* world, appropriately designed and adapted to their individual manner of conceiving reality, we may aid them in processing information and functioning accordingly.

This paper documents part of a research project under the title: "Computer-Assisted Education and Communication of Individuals with Autistic Syndrome", funded by the General Secretariat of Research and Technology of Greece and coordinated by the Department of Informatics, University of Athens. The aim of this project has been to design and develop computer-based environments for aiding the education and assessment of individuals with autism. An additional objective of the project has been to develop a web site for disseminating information and for aiding communication amongst professionals, parents and autistic individuals themselves.

Firstly, a literature review covering a range of issues regarding autism, including current ways of understanding at a biological and psychological level as well as educational – therapeutic approaches took place. At the same time, related computer-based environments for aiding autistic individuals were also reviewed. This phase led to a series of conclusions, which formulated the basis for this project, some of which are discussed in section (2) of this paper. Secondly, a pilot study took place for the purpose of testing the use of computer-based tools on children of this target group. This phase aimed at recording the responses of a range of autistic children to the use of such tools and is described briefly in section (3) of the paper.

Conclusions and observations from these two phases were taken into account in the design of a scenario (section (4) of the paper) describing in detail the exact sequence of events and consequent requirements for an interactive application that would aid the organisation of autistic childrens' behaviour in everyday activities. Finally it is suggested that virtual reality technology would be ideal for bringing this scenario to life. As this project is currently at its development phase, an indication of what has been achieved so far will be presented here.

2. COMPUTER-BASED LEARNING FOR AUTISM

The unique ways in which autistic individuals think and learn provide support for the view that the use of computers in aiding the learning process of these individuals will have many advantages. More specifically, Murray (1995) has suggested a list of characteristics provided by computer-based systems, which suit well the structured educational needs of autistics:

- clear boundaries
- controlled and step by step presentation of stimuli
- simple and obvious connection of information processed though one channel
- facilitating joint attention by selecting a compatible focus of interest
- restrictive context
- instilling feelings of safety, flexibility, adaptability and predictability of the learning environment or material
- enhancing development of autonomy, encouraging communication, boosting self-confidence and reinforcing optimism and respect.

Possible dangers involved in the use of computers for autism have been also discussed. These potential dangers can be compensated for by the appropriate incorporation of computer-based tools into a specifically organised teaching approach. It is not clear whether one could expect transfer of existing computer-based learning applications for autistic children to real world conditions. Similarly, placing such an application within an appropriate teaching context increases the possibility of achieving transfer of acquired knowledge to real world situations and consequently of enhancing generalisation (Jordan, 1995).

Taking all of the above into account, many aspects of effective learning can be promoted. In fact, several studies are in favour of the effectiveness of computers for educating autistics (Jordan & Powell, 1990, Heimann et al., 1995, Murray, 1995). The autistic child's involvement in the use of such a system may also become enjoyable without distracting from the learning target.

Virtual reality (VR) technology has already been successfully used in the treatment of phobias and in interventions to individuals with special needs. With reference to the autistic syndrome, Strickland et al. (1995) and Strickland (1997) have identified a series of VR technology characteristics, which justify its use by autistics:

- Immersive VR can isolate autistic individuals from their surroundings in order to help them focus on a specific situation.
- The complexity of a scene can be controlled.
- The lag of a VR system may not necessarily be problematic for an autistic; on the contrary it may prove useful towards aiding learning processes.
- VR technology allows for the successive and controlled adjustment of an environment with the aim of generalising activities at different but similar settings.
- A learning VE can be realistic, easily comprehensible and at the same time less hazardous and more forgiving than a real environment, when a mistake is made by the user. Thus, a VE provides us with a safe and controlled setting for developing skills for everyday life activities.
- The thought patterns of autistic individuals are mainly visual and a virtual environment (VE) builds on this specific visual skill.
- The present state of VR technology focuses on visual and auditory instead of haptic or other sensory stimuli. Specifically for autism, vision and hearing have proven to be very effective in the development of abstract concepts (Jordan & Powell, 1990).
- The use of tracking devices affords the possibility of monitoring the activities of an autistic, allowing for a re-adjustment of the system according to user's responses. Since a significant percentage of autistics never learn how to communicate, such a system may afford the possibility of interaction with simulated environments without verbal guidance provided by educators.

These characteristics correspond to the above mentioned list of factors for an effective educational system for autistic children. Moreover, a limited set of experiments (Strickland et al., 1995) have shown an encouraging adaptation of a small number of subjects to an immersive VE. This technology offers the ability to control and adjust a synthetic environment and this may prove useful for matching the needs and expectations of autistic children and consequently for teaching autistics how to respond to real world events and situations. However, more research is needed for establishing whether autistics can generalise the learning results achieved through interacting with different types of VEs.

Finally, it has to be stressed that "a gap exists between those who know about autism and the right questions to ask and those who know about the information technology and might come up with some of the answers" (Jordan, 1995). There has not yet been any computer-based application specifically developed for the autistic population in Greece. This project aims at being a first step towards this direction. It is important to mention that the team of individuals collaborating in this project consists of both people who specialise in autism and those who specialise in information technology.

3. PILOT PHASE OF THE PROJECT

The pilot phase of the project consisted of the following stages:

- A series of different types of multimedia learning environments were selected
- Educators of autistic children were trained during an intensive course into using these learning environments
- A pilot study took place in the specialist centres that collaborate in this project (EKAP, Pamakaristos) under the supervision of the trained educators
- The educators recorded their pupils responses to the selected learning environments in a specially prepared assessment sheet and were also encouraged to freely report their own impressions regarding the overall process. This fact was of particular importance since for most of them it had been their first experience of using such a tool in an educational process.

A sample of approximately 20 pupils, who had been officially diagnosed as autistic and with different levels of functioning, participated in the pilot phase.

4. "RETURNING HOME" A SCENARIO FOR EDUCATING AUTISTIC CHILDREN IN EVERYDAY TASKS

4.1 Background to the scenario

The essence of autism as a developmental disorder lies in the uneven and characteristic pattern of developmental psychological abilities, which results in an unusual combination of weaknesses and strengths. An educational program may be based on the existing areas of strength and could aim at enhancing weaker areas for the purpose of improving the overall level of functioning of the person.

The relationship between an autistic person and a non-autistic individual could be described through the metaphor of a wall, which is often being raised between them. Autistic children discourage people who try to relate to them because they do not adapt to their habits and wishes and because they rarely disrupt the regularity of their own persistent interests. One very important consequence of this behaviour is the disruption of learning even the most basic everyday activities like eating routines, washing and dressing in a consistent way. It is even more difficult for them to represent these activities. Additionally, they do not feel the need for imitating daily activities while playing.

Verbal communication is limited and as a result autistic individuals cannot easily comprehend spoken language or pay attention to the language addressed to them, while their comprehension is limited to a concrete understanding of things. It is therefore understood that their educator cannot be supported by spoken language and dialogue for teaching useful activities and enhancing their behaviour.

These facts have led to an identification of alternative ways of communicating in combination with addressing the children's stronger areas of functioning, like visual perception. Autistic children have accurately been characterised as "visual learners". In this respect, the use of symbol-cards (or icon-cards), within a structured educational context, has proved to be very useful in overcoming certain difficulties. Whenever language understanding fails to support communication, the symbol-card along with its inherent rules offers an alternative way of "speaking": simple, unambiguous and specific. As a result, the autistic children's communication with their environment may be compensated to a certain extend.

The use of the symbol-card helps children feel comfort and even pleasure after making the effort to respond to what the card presents. The icon displayed on the card is carefully designed so as to visualise the meaning of spoken language in the best possible manner. It helps autistic children feel safe and express themselves verbally, when possible. When children are not capable of speaking, they can express their needs through a card. The use of symbol-cards during playing or other activities seems to also have rewarding results for the promotion of speech and independent performance during activities.

The well known and widely accepted TEACCH program approach incorporates the use of visual representation of things and events including symbol-cards and places them in discrete sets of sequences, thus providing good support for the above mentioned views.

4.2 Description of the scenario

According to (4.1), a scenario under the title "Returning home" was designed in the form of a simulated environment addressing the visual perception of the child. The aim of the scenario was to provide the educator with a tool, which would improve his potential for effective teaching. More precisely, the content of this scenario could help him achieve a coherent organisation of certain important everyday activities, provided that it is appropriately incorporated within an overall teaching strategy.

In fact, "returning home", including the use of cards but in its non computer-based form, is a scenario which has been used in recent years, in everyday practice with autistic children. Through our direct experience with this scenario, it has been evident that children respond well and acquire a better understanding by making use of this approach. In search for a potentially successful "returning home" scenario in a computer-based form, the significant issues of using symbol-cards, speed of presenting information, quality of colour and sound, coupling of icons and corresponding words and several other aspects were addressed by the design team. The symbol-cards used in this application are the MAKATON symbol cards, which were provided to the project by the "Makaton Hellas" official representative.

The points, which were specifically taken into account while designing the scenario for the exercise, were the following:

1. Symbol-cards should precede each presented activity so that autistic children may focus their attention and understand a series of everyday life routines like eating, dressing, sleeping etc.
2. Special attention was given to the order and speed of presentation. It has been observed that autistic children respond better when a series of events follows a certain order and when the speed with which these activities are presented corresponds with their own individual rhythm. This may rid autistic children of the stressful and chaotic behaviour by letting them know of what will happen next. The symbol-card and the appropriate point of presenting this card are always crucial for the proper execution of the exercise.
3. The colours, which surround the presented images, are pastel and continuous. They should not be very vivid as this would call off their attention and would seduce them into non-functional stimuli.
4. Autistic children perceive sounds in a very special manner. While they may not respond to a person speaking to them at all, certain not very significant sounds may easily draw their attention. In cases of children with advanced musical education, music does not seem to have an enjoyable effect on them but is simply perceived per se. Therefore, any auditory enhancement of the interactive system should be very carefully designed with the aim of activating the children but without upsetting them.
5. Specific care should be taken into writing words, either in the form of icon labels or as stand alone signs, since the «literal» mind of autistic children may make them focus on one of these words and, without interpreting the correct meaning of the word, lead them to a wrong choice of action. There is also a danger that a label under an icon may distract from the icon itself or trap them into one single letter of a word. It is therefore important that icons are relatively abstract and unambiguous.
6. Re-enactment can be seen as a method of playing. Since the mind of autistics is «literal» and lacks imaginative thinking, playing activities should also be taught. Inherent in this difficulty is the fact that autistics cannot easily distinguish between the real and the imaginative. A way of achieving this could be through clearly determining the boundaries for a certain sub-space, within which imaginary events and activities are allowed to take place. Real world events take place outside this sub-space, thus clarifying the concept of «reality» for the autistic child.

These points were seen as requirements for the application to be designed.

This application aims to be another tool for aiding the very difficult task of educating autistics. The scenario will be implemented in an individualised one-to-one base. Therefore, this tool should be somehow adaptable to the individual's level of functioning and consequent educational needs. In order to achieve such an adaptation, the application would have to provide the educator with the opportunity to:

1. Select between two modes of functionality (A and B), corresponding to individuals with a lower level of functioning (A) and to individuals with a higher level of functioning (B).
   - The former mode is relatively passive involving the individual only in pressing a button for triggering the next sequence of activities.
   - The latter mode is relatively more active, involving the individual into navigating within the simulated environment and interacting with specific 2D or 3D objects in a constrained manner.
2. Select amongst a series of certain sequences of activities to be presented to each autistic individual in a certain order.

The application presents autistic children with possible everyday activities that may take place when a child returns home. They are able to navigate within this virtual environment, follow a virtual character demonstrating these everyday activities and interact with elements of the interface (2D or 3D) in order to trigger certain actions within the scene. After the completion of an activity, a symbol-card prompts the autistic child to act in order to trigger the next activity to be executed.

The entry setting for the application presents the child with an environment, comprising an arhetypal two-storey house and a road from which the virtual character arrives by a school bus. The mother greets the virtual character, who enters the house. On entering, the child is presented with a plain, longitudinal space, from where one can access the 5 rooms of the house where activities will take place: bathroom, kitchen, child's room, parents' room and living room. Each of the rooms has a symbol-card positioned on its door to indicate its function. In mode (B), movement of the virtual character is controlled by the autistic child by making use of an appropriate input device. In mode (A), the child simply triggers one sequence after the other, automatically following the animated virtual character who executes a sequence of everyday basic activities.

Figure 1. *The virtual character demonstrating the activity of "washing hands".*

Following the brief description of the scenario, the appropriate technology for implementing this scenario was identified. This process took into account the degree to which the technology satisfied the requirements described by the scenario. These requirements dictated the design of a three-dimensional environment, within which an animated character could perform a series of activities, the autistic individual could navigate and follow the character in a relatively controlled manner and interaction with certain 2D and 3D interface elements is supported. This environment could only be implemented by making use of VR technology.

5. CONCLUSIONS

The uniqueness of the autistic syndrome and the diversity of its symptomatology has directed the scientific team of the presented paper into designing an explorative, structured environment. Specialist trainers of autistic children urge for the development of parametrical environments, which could be adjusted to each individual case of an autistic child.

Currently the application is at the development stage. After completion, an evaluation will take place, in which a number of autistic children, will participate. These children will have been assessed in terms of their language and learning abilities, as well as level of functioning.

The proposed application is not seen as a panacea. It is understood that it is difficult to find a scenario equally suitable for every autistic child. However, the relatively parametrical nature of the proposed virtual environment application is expected to compensate to a degree for this inherent problem.

At this stage, the proposed environment is primarily a tool designed for aiding autistic children educators at their very difficult task. It is also important to stress the fact that this environment does not aim to substitute existing educational approaches for autistic children but rather to enrich them. Such an application could only be utilised if it is incorporated within the context of an overall educational strategy.

The designed environment implements structured tasks for training, relative to the specific needs of these children and utilises a VE system in order to filter and control environmental distractions, which may negatively affect autistic users. It is anticipated that this filtered environment and the training structured tasks could generate the interest and provoke the engagement of autistic users. With the proposed VE, the trainer could design highly filtered, structured and controlled tasks, assisted with techniques of driven attention and paired with the corresponding communication cards, to match the individual learning needs of an autistic user. In the mean time, certain aspects of this scenario could be utilised for promoting a series of secondary skills, which could also be considered as educational targets.

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Design issues on interactive environments for children with autism

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ABSTRACT

This article addresses design issues that are relevant in the AURORA project which aims at developing an autonomous, mobile robot as a therapeutic tool for children with autism. Cognitive theories of mind-reading are discussed and related to the AURORA project. This approach is put in the broader context of interactive environments, which autonomous mobile robots are a special case of. Implications of this research for interactive environments in general, and virtual environments in particular are discussed.

1. INTRODUCTION

This article discusses the use of interactive environments (software or robotic) as learning and teaching tools for the rehabilitation of children with autism. The discussions draw upon experience gained in the AURORA project, which develops an autonomous, mobile robot as a therapeutic tool for children with autism (Dautenhahn, 1999; Werry and Dautenhahn, 1999; Dautenhahn and Werry, 2000). Conceptually, this approach is strongly related to Seymour Papert's *constructionist* approach towards learning (Papert, 1980). Such an approach focuses on active exploration of the environment, namely improvisational, self-directed, 'playful' activities in appropriate learning environments ('contexts') which can be used as 'personal media'. In the mid-1960ies Papert and his colleagues at the MIT AI LAB developed the programming language LOGO which has been widely used in teaching children. A remote controlled device (a 'turtle' robot) was developed which is moving according to a set of LOGO instructions, cf. the LEGO/LOGO Artificial Life Toolkit for children (Resnick, 1989). In 1976 Sylvia Weir and Ricky Emanuel (Weir and Emanuel, 1976) published research which used such a LOGO learning environment to catalyse communication in an autistic child. They report on their experience with a seven-year-old autistic boy and the positive effects of his explorations in controlling a LOGO turtle on his behaviour. Important differences between this project and the AURORA project are: a) the robot did not act autonomously, the child remotely operated the robot via a 'button box', b) the child did not directly (physically) interact with the robot, c) the publication gives little information on the performance of the child before start of the sessions, d) only one child was tested. Although the mobile robot was remotely controlled, this is to our knowledge the first study which uses a mobile robot as a remedial device for children with autism.

A more recent approach using more interactive rather than remote-controlled technology for rehabilitation of autistic children is taken in the Affective Social Quotient (ASQ) project, (Blocher, 1999). Here, embedded technology is used to support autistic children in learning about social-emotional cues. Short 'emotionally charged' video clips are used together with a set of physical stuffed 'dolls' (embodying one emotional expression) through which the child can interact with the movies. By touching the doll the child can match a doll with a video clip. A child can explore emotional situations by picking up dolls with certain emotions, or the system can prompt the child to pick up dolls that go with certain clips. A therapist is able to control and monitor the interactions. The system shows that human-intensive, repetitive aspects of existing behavioural therapy techniques can potentially be automated.

2. THE AURORA PROJECT

2.1 Autism

People with autism are a very heterogeneous group and it is difficult to list defining symptoms. Although we use the term autism throughout this paper it is more appropriate to use the term *autistic spectrum disorders* (ASD) which acknowledges the fact that autism occurs in differing degrees and in a variety of forms.

The National Autistic Society (NAS, 2000) lists the following triad of impairments:

1. Social interaction (difficulty with social relationships, for example appearing aloof and indifferent to other people, inappropriate social interactions, inability to relate to others in a meaningful way, impaired capacity to understand other's feelings or mental states).
2. Social communication (difficulty with verbal and non-verbal communication, for example not really understanding the meaning of gestures, facial expressions or tone of voice).
3. Imagination (difficulty in the development of play and imagination, for example having a limited range of imaginative activities, possibly copied and pursued rigidly and repetitively).

In addition to this triad, repetitive behaviour patterns and a resistance to change in routine can generally be observed, associated with a significantly reduced repertoire of activities and interests, stereotypical behaviour, and a tendency of fixation to stable environments.

Depending on what is included in 'autism', rates of occurrence are given which range between 5-15 in 10000. Instead of a physical handicap which prevents people from physically interacting with the environment, people with autism have great difficulty in making sense of the world, in particular the social world. Autism can but need not be accompanied by learning disabilities. At the higher functioning end of the autistic spectrum we find people with Asperger Syndrome. Some of them manage to live independently as adults and to succeed in their profession, but only by learning and applying explicit rules in order to overcome the 'social barrier' (Grandin, 1995; Grandin and Scariano, 1996; Schäfer, 1997). Instead of picking up and interpreting social cues 'naturally' they can learn and memorise rules about what kind of behaviour is socially appropriate during interaction with non-autistic people. Autism is not, as has long been assumed in public, a voluntary decision to retract from the world: people with autism do not have the choice to live socially or not, the decision has been made for them.

Two different viewpoints exist on how to connect the autistic with the non-autistic world: either efforts are undertaken to teach people with autism the skills they need to survive in the world of 'normal' people, or it is suggested that they might be happier living separately in a world specifically designed for them. From all what we know about the way individuals with autism feel (see books written by Temple Grandin and others), they are painfully aware of their 'being different' from other people, and express the wish to be part of the 'world outside'. Accepting the differences, empowering people with autism, and linking their world with the world that non-autistic people are living in poses many challenges. In order to understand people with autism we have to understand better the causes of autism, and can find ways to empower them, including computer and robotic technology, so that they have the choice of whether and to what extend they want to connect to the world of non-autistic people.

2.2 Socially Intelligent Agents

Recently *Socially Intelligent Agents* research has resulted in a variety of different software and robotic systems which can successfully interact with humans and show aspects of human-style social intelligence (for an overview see Dautenhahn and Numaoka 1998; Dautenhahn and Numaoka, 1999; Dautenhahn 2000; SIA, 2000). Interesting interactive robotic systems are the KISMET platform (Breazeal and Scassellati, 1999) and the ROBOTA dolls (Billard et al, 1998; Billard, 2000). KISMET is a humanoid face that can generate expressive social interactions with human 'caretakers'. Such 'meaningful' interactions can be regarded as a stepping-stone for the development of social relationships between a robot and a human. The ROBOTA dolls are humanoid robots developed as interactive toys for children and are used as research platforms in order to study how a human can teach a robot, using imitation, speech and gestures. Increasingly, robotic platforms are developed as interactive playmates for children (e.g. Montemayor et al, 2000; Canamero and Fredslund, 2000). Besides commercial purposes (see Sony's Aibo robot), such interactive robotic systems can potentially be utilised as learning environments and in rehabilitation applications, as studied in the AURORA project.

Figure 1. *The two photos on the left show two children with autism interacting with the Labo-1 robot. The left photo demonstrates what we mean by 'eye-contact' in the case of human-robot interaction. The middle photo shows a child who played with the robot for an extended period of time until he needed to go back to class. Most of the time the child was lying on the floor and playing 'interaction games' with the robot, i.e. reaching out and touching the robot which then caused the robot to approach/avoid the child. The photo on the right shows Labo-1 in more detail. The basic sensor configuration consists of active infrared sensors for obstacle avoidance and pyro-electric sensors which allow detection and following of humans. The robot weighs about 6.5 kg. Due to a 4 wheel differential drive it can turn very smoothly. The robot can manage a few kilograms of additional weight, e.g. when children are pushing the robot or (partially) stepping on it. Words and simple phrases are produced by the robot in certain situations, by means of a voice production device (not shown). In the trials the robot moves very slowly, so that even when it bumps into a child (what rarely happens since the children are very attentive to the robot's movements) no harm is done. The robot is robust enough to cope with being extensively pushed around during the trials.*

2.3 Brief Project Description

Since end of 1998 the project AURORA (AUtonomous RObotic platform as a Remedial tool for children with Autism) investigates how an autonomous mobile robot can be developed into a remedial tool in order to encourage children to become engaged in a variety of different interactions that possess features which are important elements of human social behaviour (eye-contact, joint-attention, approach, avoidance, following, imitation games etc.). Figure 1 shows the robot that is used in the AURORA project. The children who are interacting with the robot are between 8-12 years of age, including children who are non-verbal, i.e. they cannot use language or usually do not use language.

In the rehabilitation of children with autism therapeutic issues (e.g. eye contact, joint attention, turn taking, reading mental states and emotions) are usually addressed in constrained teaching sessions (Howlin et al, 1999). In contrast, robot-human interactions in the AURORA project are unconstrained and unstructured, the children are allowed to interact with the robot in whatever position they prefer (e.g. lying on the floor, crawling, standing, cf. Figure 1), they are also free to chose how they interact with the robot (touching, approaching, watching from a distance, picking it up etc.). Interference is only necessary if the child is about to damage the robot or if the child (by pressing buttons) switches off the robot so that it needs to be restarted. Such conditions are much different from other projects on robot-human interaction (e.g. KISMET, or the ROBOTA dolls) where the human is expected to interact with the robot while adopting a particular position and orientation towards the robot (e.g. sitting face-to-face in close distance to an interactive robot that is not moving in space). The particular challenges faced in the AURORA project, in the broader context of rehabilitation, together with a more detailed discussion of therapeutical issues involved, is given in (Werry and Dautenhahn, 1999; Dautenhahn and Werry, 2000).

2.4 Theoretical Background and Working Hypotheses

The AURORA project deliberately uses a non-humanoid robot, based on the observation that children with autism prefer a predictable, stable environment and that many people with autism have difficulty interpreting facial expressions and other social cues in social interactions. Consequently, they often avoid social interactions since people appear unpredictable and confusing. Generally, using a robot as a remedial toy takes up the challenge of bridging the gap between the variety and unpredictability of human social behaviour (which often appears frightening to children with autism) and the predictability of repetitive and monotonous behaviour which children with autism prefer and which can be performed by mobile robots (see discussion in Dautenhahn, 1999).

We hypothesise that a child with autism 1) is sufficiently interested in 'playing' with an interactive autonomous robot as it is used in the AURORA project, 2) the robot can engage the child in interactions which demonstrate important aspects of human-human interaction (e.g. eye-contact, turn-taking, imitation games), and 3) (as a long term therapeutic goal), while slowly increasing the robot's behaviour repertoire and the unpredictability of its actions and reactions, the robot can be used to guide the children towards more realistic and 'complex' forms of social interactions resembling human-human interaction. This approach is based on two areas of theoretical work.

2.4.1 Mindreading. Generally, humans are from an early age on attracted to self-propelled objects which are moving autonomously and seemingly with 'intention' (Dautenhahn, 1997). In (Premack and Premack, 1995) a *theory of human social competence* is presented that consists of three units: the first unit (*intentional system*) identifies *self-propelled movements in space* and interprets them as intentional, engaged in goal-directed behaviour, such as escaping from confinement, making contact with another intentional object, overcoming gravity (e.g. seeking to climb a hill). Animate and inanimate objects are distinguished since only animate objects can move both in space and time without the influence of other objects. Movement in place is interpreted as animate but not intentional. The second unit is the *social system* which specifies the changes that the intentional objects undergo. It allows to interpret relations e.g. as possession or group membership. The third unit is the *theory of mind system*, which outputs explanation, states of mind, perception, desire, belief, and its variations. These mental states are used to explain the actions.

Effects of the 'intentional stance' produced by the above mentioned mechanisms, in particular the intentional system as the basic unit which selects the objects to be considered, are convincingly demonstrated in (Heider and Simmel, 1944). Here human subjects created elaborate narratives about intentional agents when asked to describe movements of moving geometric shapes shown in a silent film. A more general *behaviour reading* mechanism is also suggested as the basis for anthropomorphism (Mitchell and Hamm, 1997): evidence indicates that for evoking anthropomorphic interpretations the *behaviour* of objects (in Mitchell and Hamm's study animals) is more important than other aspects, e.g. the appearance of an object, or whether a human is familiar with the object. We suggest that the same might apply to inanimate objects such as robots. Every robotics researcher who has ever given a demonstration of autonomous mobile robots to a general audience can confirm how readily humans view robots as people (Bumby and Dautenhahn, 1999).

Premack and Premack's theory of human social competence shows great similarity with Baron-Cohen's suggestion of four mechanisms underlying the human *mindreading system* (Baron-Cohen, 1995). The first mechanism is the *intentionality detector* that interprets motion stimuli (stimuli with self-propulsion and direction) in terms of the mental states of goal and desire. These primitive mental states are basic since they allow making sense of universal movements of all animals, namely approach and avoidance, independent of the form or shape of the animal. The ID mechanism works through vision, touch and audition and interprets anything that moves with self-propelled motion or produces a non-random sound as an object with goals and desires. The second mechanism as part of Baron-Cohen's mindreading system is the *eye-direction detector* (EDD) which works only through vision. The EDD detects the presence of eye-like stimuli, detects the direction of eyes, and interprets gaze as *seeing* (attribution of perceptual states). This mechanism allows interpreting stimuli in terms of what an agent sees. ID and EDD represent *dyadic relations* (relations between two objects, agent & object or agent & self) such as 'Agent X wants Y' or 'Agent X sees Y', however they not allow to establish the link between what another agent sees and wants and what the *self* sees and wants. Sharing perceptions and beliefs is beyond the 'autistic universe', it requires the additional mechanisms SAM (shared-attention-mechanism, allows to build triadic representations: relations between an agent, the self, and a third object) and ToMM (theory-of-mind mechanism). ID, EDD, SAM and ToMM make up a fully developed human mindreading system as it exists in biologically normal children above the age of four. In normal development, from birth to about 9 months a child can only build dyadic representations based on ID and basic functions of EDD. From about 9 to 18 months SAM comes on board and allows triadic representations that make joint attention possible. SAM links EDD and ID, so that eye direction can be read in terms of basic mental states. From about 18 to 48 months ToMM comes on board, triggered by SAM. The arrival of ToMM is visible e.g. through pretend play. Note, that earlier mechanisms are not replaced by newer ones, they still continue to function. According to Simon-Baron's analysis children with autism possess ID and EDD. ToMM is missing in all children with autism while some of them possess SAM.

Referring to this theoretical framework, the working hypotheses (section 2.4) studied in the AURORA project clearly address the ID and EDD mechanisms. In the same way as biologically normal children above 4 years of age detect, are attracted to, and interpret autonomous, self-propelled objects such as robots as 'social agents', we hypothesise that children with autism can accept a mobile robot as a social agent.

2.4.2 Interaction Dynamics. The second strand of theories which the AURORA project is influenced by concerns interaction dynamics between babies and their caretakers as studied in developmental psychology (e.g. review articles in Meltzoff, 1996; Meltzoff and Moore, 1999). A more detailed account of these issues and their relevance in the AURORA project is given in (Dautenhahn and Werry, 2000), and we can only present a brief summary here. Infants seem to detect specific temporal and structural aspects of infant-caretaker interaction dynamics. It is suggested that turn-taking and imitation games allow the infant 1) to identify *people* as opposed to other objects, and 2) to use the *like-me-test* in order to distinguish between different persons. Motivated by this research we suggested a conceptual framework in order to classify different and increasingly complex dynamics in robot-human interactions (Dautenhahn and Werry, 2000). Within this framework, robot-human interactions in the AURORA project are designed where synchronisation of movements*, temporal coordination*, and the emergence of imitation games are used as important mechanisms for making 'social contact' between the robot and the child. It is hoped that such an approach which focuses on interaction dynamics rather than cognitive reasoning mechanisms can incrementally facilitate and strengthen temporal aspects which are so fundamental to the development of social competence and the ability to socially interact with people (cf. Hull, 1983).

2.5 *Summary of Results*

Initial trials in the AURORA project stressed the individual nature of the specific needs of children with autism, but they also showed that most children responded very well and with great interest to the autonomous robot. In a recent series of comparative trials where the children were playing with the robot (condition 1) and also (separately) with a passive non-robotic toy (condition 2) children showed greater interest in interactions with the robot than with the 'inanimate' toy (quantitative data will be published in a forthcoming publication by Werry and Dautenhahn). Also, children showed increased interest in the front part of the robot where the pyro-electric sensor is attached, a sensor with strongly eye-like features (eye-like shape, located at the distal end of the robot's preferred direction of movement, prominent position raised above the chassis, direction of the sensor changing according to 'gaze'). These observations seem to confirm our hypothesis that interactions in the AURORA project can successfully built on mechanisms of intentionality detection (ID mechanism) and eye-direction-detection (EDD mechanism).

The following section discusses how the design issues, which the AURORA project is based on, could be applied to other interactive technologies, e.g. virtual environments.

3. IMPLICATIONS FOR INTERACTIVE VIRTUAL ENVIRONMENTS

We suggest that the following design issues might generalise from the AURORA project to other interactive environments designed as remedial learning environments for children with autism. The discussions focus on the potential of virtual environments as remedial tools for children with autism.

Controlled and safe learning environments. The *autistic spectrum disorders* cover a huge range of different abilities and needs of the children. Even within particular age ranges individual differences can be immense. The target group therefore needs to be identified very clearly, but even then interactive environments need to account for individual needs of the children. Virtual environments can be designed as learning environments (e.g. Cobb et al, 1998) and for rehabilitation (e.g. Wilson et al, 1997), and this technology has also great potential for children with autism (Kijima et al, 1994; Strickland et al, 1995; Strickland, 1996). In such environments input stimuli can be controlled and the behaviour of the child can be monitored. Successive learning sessions can be evaluated in order to monitor progress of teaching objectives, controlled by the teachers. Environments can be customised to account for individual differences. Children can be guided through learning experiences and explore new behavioural opportunities by themselves. Such environments can provide safe environments without or with little intervention by another human, although teachers and/or parents (family) of the children are usually important participants in trials with autistic children. Dorothy Strickland (Strickland, 1996) gives an example of a virtual environment that is used as a learning environment for children with autism. Such environments can partially replace time-consuming, routine teaching sessions, if they are properly integrated with the curriculum and teaching method used in the schools. Alternatively, such environments could be built for use at home, in a playful and exploratory context where children might use the environment in a more creative way. Enjoyment and an increase of the children's quality of life is a goal as desirable as skill learning (cf. Cobb et al, 1998).

Proactive behaviour: In contrast to other children, which enjoy a lively, dynamic and even 'messy' playground, children with autism prefer a predictable, structured and in this way 'safe' environment. The child prefers to be in 'control' of the interaction. The NAS schools use a system known as TEACCH (Treatment and Education of Autistic and related Communication handicapped Children, Watson et al, 1989). This system has been developed to encourage the autistic child to explore and develop pro-active skills and uses a system of stimulus and response. Like other behavioural approaches TEACCH emphasises structure, specific behaviours are targeted, conditions and consequences of eliciting the behaviour are defined, and behaviour is shaped through the use of cueing and prompting. Functionality (behavioural view) and pragmatics (psycholinguistic view) are the central issues in the TEACCH methodology. "More meanings for more purposes in more situations" are taught prior to teaching communication with more complex forms (Watson et al, 1989). Naturalistic, less structured settings with naturalistic consequences are preferred to artificial settings. The TEACCH curriculum addresses a wide spectrum of communicative functions (request, get attention, reject or refuse, comment, given information, seek information, express feelings, social routine) and forms of communication (motoric, gestural, vocal, pictorial, written, sign, verbal). A robotic agent is able to complement this approach as it can prompt through behaviour in a constant and predictable manner. In this way, initiative-taking and spontaneous communication can be encouraged.

Embodied Interaction: Virtual environments as described in (Strickland, 1996) require that the children are wearing VR helmets. This might be appropriate for some children, but we can expect that this in not feasible for many autistic children. Here, 'non-tethered' approaches can be investigated. Particularly promising seem approaches which support interactions involving the whole body, in set ups where the child can freely move, i.e. when the child is not constrained to sitting at a desk, is not required to wear special devices, and is not 'tethered' in any way. Such environments can particularly well address the dynamics of social interactions. Children with autism often show a distorted and usually 'indifferent' attitude towards their body. Self-injurious behaviour, abnormal complex behaviours of the body and eating disorders can be observed. These indications of body image distortions might contribute to their problems in relating to other people. Schools of the NAS have playrooms and various different facilities in order to support multi-modal and bodily experiences. As explained above, interactive environments can provide learning environments more sophisticated and controllable than those commonly used, based on common teaching practises, e.g. addressing issues of visual perception, mindreading and general problem solving. Additionally, interactive environments can explore new teaching practises based on an exploratory and playful approach involving the 'complete child', namely involving physical movement. In contrast to traditional approaches, robotic and other interactive environments (cf. Bobick et al, 1999; Penny, 2000) can allow the child to move around 'freely' or less constrained than when confined to a chair. The issue of embodied interaction can provide new aspects to learning environments, e.g. helping children with autism to explore their bodies and how the body interacts with the environment. Thus, the bodily interaction itself can be as therapeutically relevant as the 'content' of the interaction.

Generalisation: A major problem of all therapeutic approaches to autism is generalisation: a child often shows improved performance in the particular teaching environment (e.g. in classroom) but it has great difficulty in generalising the learning experiences and applying the newly acquired skill to non-classroom situations. In particular virtual environments have an enormous potential here: creating different contexts and environments in the classroom and changing features and shapes of objects in the environment is very time-consuming and often infeasible, while creating alternative scenarios or variations in virtual environments is comparatively easy. This is important for specific learning objectives as well as for a more broader approach, e.g. the general facilitation of imaginative skills. To give an example: If a teacher enacts a story together with children, then the colour of a blanket cannot be changed instantaneously, neither can a sword suddenly appear out of thin air. Normal children can easily compensate for these 'deficiencies' of the real world, their imaginative skills allow to create different worlds, alternative or fictional realities, as it is shown in role-play. However, the imaginative skills of children with autism are often impaired, they prefer the concrete, the visible. The shape of a robot cannot change suddenly; it cannot grow wings and fly away. However, in virtual environments rich, dynamic, and at the same time concrete and visible worlds can be created, although mostly limited to the visual (a child doesn't get wet if it starts raining, the feeling of raindrops on the skin cannot be experienced 'virtually').

Presence: The issue of 'presence' in virtual environments has been discussed intensively for many year (e.g. Heeter, 1992), and the acceptance of virtual environments does strongly depend on whether the user's presence in the artificial environment is believable, i.e. whether he or she has the impression of 'being there'. Often reality is confusing to a person with autism; clear boundaries, meaning, and order seems to be missing. Thus, for children with autism the feeling of 'being there' in the real world is different from what we experience. Possibly, virtual environments will intensify the impairment of presence, and the feeling of 'alienation'. Thus, particular attention is necessary in order to ensure that experiences in virtual environments are made *real* and *meaningful*, namely providing the link to experiences in the real world. Using interactive physical robots avoids this problem, interactions are not necessarily natural but they are grounded in experiences in the real world. However, their interactive abilities (e.g. range of different behaviours), in comparison to software environments, are currently limited.

Holistic perception. People with autism have difficulty in 'holistic perception', namely integrating different perceptual inputs (e.g. merging different perspectives of the same object/person to a *concept* of an object/person). Typically, children with autism will tend to focus on details in an environment and not on the 'whole picture'. For example, if an object is presented to the child one cannot assume that the child directs his/her attention to the object as a whole, it is likely that the child's perception will focus on *aspects* of the object, e.g. colour, shape, structural details etc. In particular a virtual environment seems to be well suited to address this issue, e.g. different aspects of the world can be highlighted, dynamically changed (depending on the child's activities), presented differently etc.

4. CONCLUSION

This article introduced the project AURORA and discussed particular challenges and problems involved in building interactive robotic systems as therapeutic teaching devices for children with autism. Experiences from this project were discussed in the context of virtual learning environments. It is hoped that the development of robust and believably interactive systems (robotic and software) can support the rehabilitation of children with autism, so that ultimately such technology can become an integrated part of the curriculum, being used by teachers and parents and tailored towards specific individual needs of children with autism. To provide an enjoyable and entertaining 'toy' specifically adapted to the needs of the children and increasing the quality of life of children with autism, is an integral part of the AURORA project. However, helping children with autism to develop social skills is methodologically and technically more demanding. Given the nature of autism only long-term studies will reveal if and how this goal can be met.

A *design space* of interactive environments needs to be explored (comprising possible designs of interactive systems) and linked to the space of sets of requirements which Aaron Sloman called *niche space* (Sloman, 1995). One might speculate that (different types of) robotic therapeutic tools might map to (different sets of) requirements addressing primarily bodily, physical interaction, while (different types of) virtual environments might map to (different sets of) requirements addressing primarily imaginative and cognitive skills. There might be niches for various types of interactive environments and socially intelligent agents which could be used in the rehabilitation of children with autism, e.g. humanoid and non-humanoid robots, multi-media interactive environments, and virtual environments ranging from desktop VE's to immersive interactive learning and play environments (Bobick et al, 1999; Penny, 2000). Among the big challenges is the development of appropriate design methodologies and evaluation methods, so that different interactive environments and their effectiveness in the application domain of autism therapy can be assessed and compared.

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Development of social skills amongst adults with Asperger's Syndrome using virtual environments: the 'AS Interactive' project

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ABSTRACT

People with High-Functioning Autism, or Asperger's Syndrome (AS), are characterised by significantly impaired social understanding. Virtual environments may provide the ideal method for social skills training because many of the confusing inputs in 'real world' interactions can be removed. This paper outlines the rationale and methodology of the *AS Interactive* project. This multidisciplinary project incorporates a user-centred design and aims to develop and evaluate the use of virtual environments to support and enhance social skills amongst adults with AS. The potential for the use of Collaborative virtual environments for developing social awareness is also discussed.

1. INTRODUCTION

1.1 Background to Autism and Asperger's Syndrome

Asperger's Syndrome is a sub-category of the pervasive developmental disorder Autism (DSM-IV, American Psychiatric Association 1994). Autism is a "spectrum" disorder (Wing, 1996), ranging from 'classic' autism with severe learning disabilities at one end, to high functioning autism (HFA) and Asperger's Syndrome (AS) at the other. In between lie people with autism or autistic-like behavioural syndromes, with varying degrees of associated learning disability. Although IQ levels vary along the spectrum, all individuals diagnosed with an autistic spectrum disorder are defined by specific deficits, including a marked impairment in social skills. The difficulty with social interaction is manifested by a lack of reciprocity and restricted ranges of interests and behaviour (Nordin & Gillberg, 1998). People with autism often show abnormalities in the use of language, including egocentric and/or echolalic speech (repetition of words or phrases) and an overly literal interpretation of words and phrases. A limited understanding of social norms and expectations may often lead to inappropriate behaviour and can result in difficulties forming and sustaining friendships. An anecdotal report from Temple Grandin – an American academic with AS – indicates just how difficult social situations can be: "[she avoided dating]…finding such interactions completely baffling and too complex to deal with…[because]…she was never sure what was being said, or implied, or asked, or expected" (from Sacks, 1995; p.272).

Like Temple Grandin, many people with AS or HFA manage to achieve high levels of academic achievement and live independently (e.g. Szatmari, et al, 1989). Indeed, IQ is the best known predictor of outcome for people with autism spectrum disorders (Nordin & Gillberg, 1998). People with AS tend to have relatively normal levels of cognitive skills and tend not to exhibit early language delays (Howlin, 1998). Their narrow range of interests and often, obsessive focus on one particular topic may lead to superior knowledge in a specific area of expertise. Nevertheless, despite relatively good outcome in terms of academic attainment and personal/life skills, people with HFA and AS remain significantly impaired in social understanding (Gillberg, 1998; Nordin & Gillberg, 1998). This can lead to social exclusion and failure to maintain employment due to difficulties in making friendships and communicating ideas. Depression, and other secondary psychiatric disorders, are especially common amongst people with HFA and AS (Tantam, 1988), and there is a higher than average incidence of suicide within this population (Wing, 1981).

1.2 General use of computers in Autism

Due to the difficulties with social interaction that people with AS face, the idea of providing less threatening situations in which skills can be practiced and learned seems intuitively appealing. Computer assisted learning (CAL) has been suggested as an ideal way to present information in a way that reduces the potentially confusing and anxiety-inducing, multi-source inputs that characterise 'real world' social interactions (e.g. Moore, 1998; Moore, et al, 2000). For example, there are non-verbal features (such as gestural, postural and facial information) and verbal features of communication (such as intonation and other paralinguistic cues). A computer-based environment may present an ideal medium for reducing the number, frequency and saliency of this type of information; thereby allowing basic skills to be learned in the absence of competing and distracting cues. Additionally, Swettenham (1996) suggests that computers may be especially appealing to people with autism because they provide a consistent and predictable environment in which the pace of working can be suited to individual needs.

There is some evidence to suggest that computers can lead to successful learning outcomes for people with autism. Heimann, et al., (1995) used an interactive multimedia computer program to teach reading and communication skills to children with autism. Children showed significant vocabulary gains during the training period, and were highly motivated by, and interested in, the computer-based tasks (similar results have been found for teaching language to children with other communication disabilities; Schery & O'Connor, 1997). Chen and Bernard-Opitz (1993) directly compared personal instruction to computer-assisted instruction for four children with autism on a number of tasks. Increases in motivation and decreases in problem behaviours were noted during computer-based instruction, but this was not accompanied by significant improvements in learning (compared to personal instruction). However, there were only four children included, all of whom were young (aged 4-7 years) and relatively low-functioning. Low mental age might account for the failure to demonstrate significant improvements in knowledge gain. Individuals with higher IQ might fare better with CAL approaches.

Targeting older participants and focusing on social understanding, Rajendran & Mitchell (2000) employed a Bubble Dialogue program in which two adults with AS could type in thought and speech content for story protagonists in a variety of social situations. The dialogues were useful in helping people with AS to consider the implications of thought and speech in social situations. However, there were no indications that the intervention with the bubble-dialogue program improved the participants' interpersonal understanding in the 'real world' (based on scores from a behavioural checklist developed by Frith, et al., 1994). Many other studies have attempted to teach people with autism how to improve their understanding of other people's mental states i.e. their 'mentalising' ability (e.g. McGregor, et al., 1998a & b; Hadwin, et al., 1996; Swettenham et al., 1996; Ozonoff & Miller, 1995). This ability is crucial for understanding why others behave in particular ways, and for interpreting language in terms of what the speaker *means* (rather than simply what they *say*). However, all have indicated that participants fail to generalise the rules learned during instruction to other, novel, tasks. This is also true of one intervention that used a computer to teach mentalising rules to children with autism (Swettenham, 1996).

Overall, interventions that have tried to teach people with autism about other's mental states have met with limited success. Computer-based tasks, on the other hand, have been somewhat successful in teaching reading and language and have proved to be motivating and fun for people with autism. However, Howlin (1998) voices concern over the use of computers for people with autism. She suggests that care needs to be taken when using computer-based tasks because they could encourage reliance on the non-human interaction of the computer. This could lead to an obsession with the technology and a resultant decline in 'real' social interaction. Consequently, Howlin suggests that some social interaction should be incorporated alongside CAL, but ideally, social skills training should take place *in situ.* The problems with *in situ* social training are that it can be extremely labour intensive, difficult to manage, and incorporates all of the elements of social interaction that people with autism find threatening, confusing and frightening.

1.3 The value of virtual environments for people with Autism

Virtual environments (VEs) may provide the ideal method for social skills training: a computer-based task which can control the level of inputs the user receives, but shares more features in common with the 'real world' through the use of sophisticated graphics and design. The shared features between virtual and real worlds may facilitate the generalisation of skills from the former to the latter. The lack of shared features between previous training tasks (summarised above) and the 'real world' may, in part, explain the difficulties experienced in trying to utilise learned skills in more naturalistic settings. Moreover, VEs could incorporate a certain level of social interaction through the participation of carers/parents sitting alongside the person with autism (Murray, 1997), as found in the use of desktop virtual environments (Neale, 1997; Neale et al., 1999). This could help to assuage the concerns of those who fear that the computer could become the only source of interaction that the person with autism finds tolerable.

Clancy (1996) describes the usefulness of VEs for people with particular disorders, including autism (also Trepagnier, 1999). The main benefit of VEs is that users can practice skills safely, without experiencing potentially dangerous real world consequences. For example, patients can experience a 'virtual airplane' in the hope of attenuating flying phobia, or children with autism can learn the rules of how to cross the road safely. A one-day seminar organised jointly by the U.K. National Autistic Society and the University of Nottingham also concluded that VR technology could be an extremely useful approach for teaching life skills to people with autism (Neale, 1998). This was based on the work of VIRART at the University of Nottingham, who developed a Virtual City for children and adults with learning disabilities to learn and practice a series of everyday skills leading towards independent living (The Life Skills project: Brown et al., 1999). Scenarios within the program represent procedures and task sequences such as selecting items in the supermarket and paying for them, planning a bus journey, ordering food and drinks in a café and preparing a meal in the home.

Generally, there is much anecdotal support for the possibility of using VEs to facilitate social skills in people with autism. However, there is a paucity of direct evidence to support the idea. Strickland (1996) presents one of the few attempts to expose people with autism to VEs. She applied a fully immersive VR system, including a headset, to two young, minimally verbal children with autism. The VE consisted of a simplified street scene, which, periodically, showed a car moving down a street. Both children behaved as if they were tracking the cars down the street (by turning their head and body in the right direction) and walked towards objects in the virtual world. Whilst this may provide preliminary support for the idea that children with autism can use virtual environments, there is a long way to go before instances of knowledge gain can be demonstrated using this approach. Moreover, although it is stressed in the paper that VR headset wearing was not forced, it is clear that they were not popular with the children. One child took three sessions (within a 15 minute period) to accept the headset and sweets had to be used as enticements. Additionally, the children were unable to verbally express any discomfort at the wearing of the headset, but when they started to support the heavier, front of the headset, with their hands it became noticeable that they were not comfortable with it.

Eynon (1997) avoided the difficulties associated with fully immersive VR in his AVATAR program, instead preferring to use desktop VEs (i.e. a user/computer-screen interface). These were developed in conjunction with VIRART and based on the Virtual City's 'House World.' Children with autistic spectrum disorders were included in the initial pilot phase of the study, and three children with 'communication disorders' formed the final participant group. Trials suggested that the children were attentive, could focus on the presented activities and achieved meaningful interaction with the program. However, the usefulness of the AVATAR project for people with autism is not clear since specific diagnoses, ages and cognitive abilities of the children were not reported. Nevertheless, the study suggests that a desktop interface could be a useful approach for children with communication disorders. Interaction with objects within the environment can be mediated by interaction with another person sitting alongside the user.

1.4 Collaborative virtual environments and social interaction

Another way of achieving 'social' interaction through VEs is through the use of Collaborative VEs (CVEs). CVEs allow participants to share the same virtual world over a computer network. There are a number of defining features of CVEs (Benford, et al., 1994):

(1) Navigation: each participant steers their own viewpoint through the world.

(2) Embodiment: each participant is directly represented by a graphical object called an 'avatar'.

(3) Communication: participants may exchange messages using some combination of audio, video, text and graphics.

(4) Interaction: participants may directly manipulate virtual objects within the world.

These features could have direct value for people with autism. In particular, more 'realistic' social situations can be presented via the computer because participants can interact with each other and communicate in a variety of ways. This means that interaction within the virtual world can be more dynamic and flexible (like the real world, and unlike the fixed response patterns within single-user VEs), but less threatening for people with autism due to a number of factors:

(a) The user has *active control* over their participation in the environment. This may boost confidence for people who feel 'out of control' in normal social situations.

(b) Interaction can take place *without face-to-face communication* (Hindmarsh et al., 1998), which many people with autism find particularly threatening.

(c) The level and number of non-verbal and verbal features of communication can be *directly controlled* and manipulated.

(d) Interaction takes place within an environment that is *stable and familiar*, unlike the constantly changing real world environment.

(e) Communication can occur in a *slower-paced* environment. CVEs tend to offer slower, less responsive reactions than in physical environments, but participants have been shown to develop adaptive strategies as a way of coping with these (Hindmarsh, et al., 1998). Slowing down the rate of interaction may provide time to think of alternative ways of dealing with particular situations.

(f) Participants may use different equipment to access the same CVE, enabling people with *varying levels of ability* to interact together.

(g) CVEs can be tailored to *individual needs* in terms of features of the environment that can be manipulated. Individualisation may be crucial to the success of intervention or instruction (Higgins & Boone, 1996).

The combination of these benefits makes the use of CVEs as aids to the development of social skills an extremely interesting and exciting prospect. Indeed, the appearance of chat rooms on the Internet specifically catering for people with AS (e.g. 'Aspiechat'; see Reference section for details) suggests that multiple users can use the same virtual environment effectively. However, given the lack of systematic research into the usefulness of VEs for people with autism, any research project must first address usability issues of single-user VEs before moving on to investigate whether CVEs offer additional advantages. The following section outlines how we intend to approach these challenges in the *AS Interactive* project.

2. PROJECT RATIONALE

Summarising the background literature: people with autism and AS suffer severe impairments in social skills and understanding; traditional approaches to developing social skills through teaching 'mentalising' rules fail to show any real world benefits; computer-based learning has distinct advantages for people with autism; VEs and CVEs present potentially valuable settings for providing a new approach to social skills development; and there is a need for new and systematic research into the value and benefit of VEs and CVEs for people with autistic spectrum disorders. In response to these points, the overall aim of the *AS Interactive* project is to develop and evaluate the use of virtual environments to support and enhance social awareness and social skills amongst adults with AS.

According to Howlin (1998), people with AS are "… the least well served or understood " and "…may require even more highly specialised help than those with global learning difficulties" (p.317). This is because people with AS are often required to 'fit in' to the 'normal' world due to relatively normal cognitive abilities and (often misleading) competence in the use and understanding of language. However, severe impairments in understanding the subtleties of social interaction, coupled with some insight and knowledge of their disorder, leaves people with AS extremely vulnerable, anxious and in need of appropriate help. Facilitation of social skills in work-related situations may be particularly important since the ability to gain and maintain employment contributes significantly to overall feelings of capability and higher self-esteem. Consequently, one of the eventual aims of the project is to focus on social skills that might be especially relevant to work-related contexts.

AS Interactive is a three-year program of research and development funded by the Shirley Foundation, which started in April, 2000. It combines expertise in autism research with expertise in VR technology development and its application for users with special needs at the University of Nottingham. Collaboration with the U.K.'s National Autistic Society will ensure that the needs of the users are addressed and help steer the project towards a useful and usable end-product. The researcher from the NAS (L.B.) is responsible for recruiting users with AS from schools and social groups. He will also play a key role in the evaluation and assessment of the appropriateness of the design and content of VEs for people with AS. Initially, the project aims to assess the potential feasibility and acceptability of VEs for adults with AS. Both single-terminal and collaborative VEs will be reviewed in order to identify features that will be useful for social skills training, and define a suitable interface for users with AS. Ultimately, it is expected that CVEs will be developed replicating one, or more, work-related contexts; these will be available to a wide range of users on the Internet. Specific social interaction scenarios will be built in to these environments to allow training and practice of appropriate social skills.

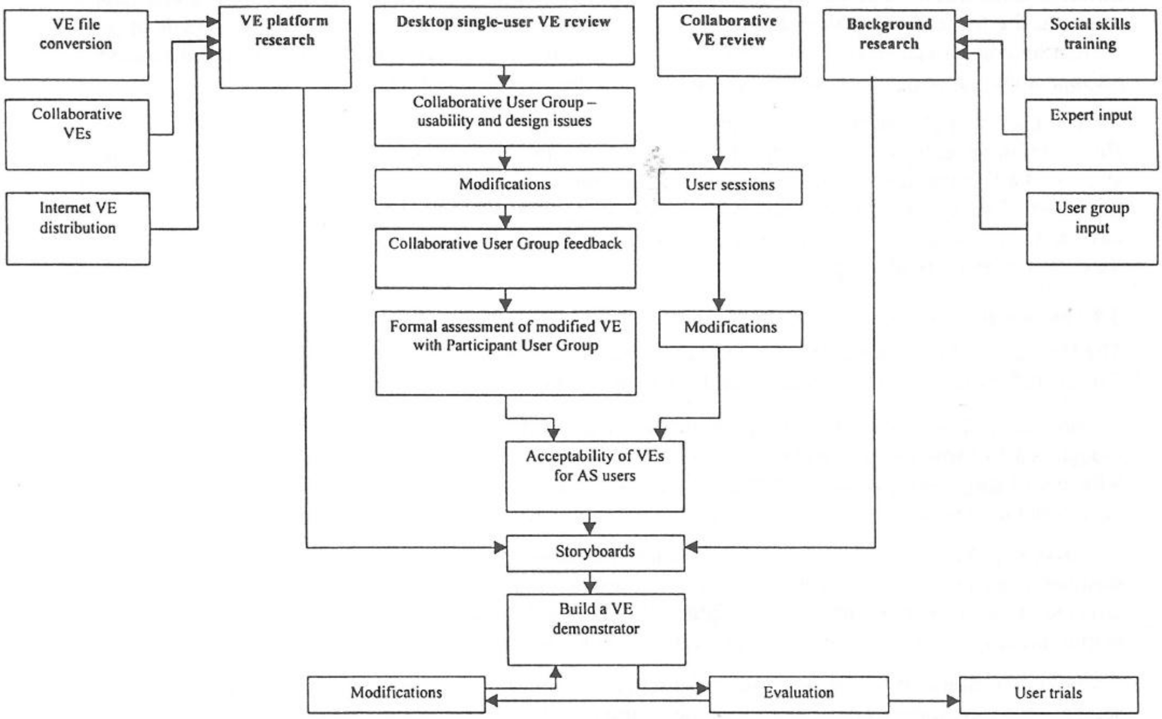

Figure 1. *Model of the design and development process of virtual environments for people with Asperger's Syndrome.*

3. METHODOLOGY

3.1 User Groups

Following from the research methods successfully employed during the Life Skills project (Brown, et al., 1998; Cobb et al., 1998; Meakin et al., 1998), *AS Interactive* will employ a user-centred design and evaluation methodology. Two groups of users are involved in the project. A summary of their roles clarifies how the user groups will contribute to the design and development of particular VEs (see also Figure 1 which provides a model of the design and research process).

A. The **Collaborative User Group** consists of adults recruited from a social group for people with Asperger's Syndrome. This group will be involved in an iteration process of review and development of an existing VE. That is, they will advise the research team about the appropriateness and usability of VEs for people with AS and will help to inform design specifications for future VE development. Initially, single-terminal VEs will be presented to the group members for comments. A few members of the Collaborative User Group will also assess CVEs. The particular CVE to be reviewed is yet to be decided, but will be guided by the responses to the single-user VE trials in order to identify suitable tasks. Feasibility and acceptability are key considerations in the development of CVEs since they have not previously been employed with special needs users.

B. The **Participant User Group** comprises adolescents with AS, aged 13-19, who have been recruited from special needs schools. This age group represents the target user population because it includes individuals who are working towards transition from school to work or college, and those who are very close to it ('transition' programmes within schools tend to start with pupils from around the age of 13/14 years). Therefore, this group could benefit directly from work-related social skills training at a time when moving in to a work environment is a priority. The participant group(s) will be included in formal studies to evaluate the suitability and usefulness of virtual environments for social skills training.

3.2 What VE will be reviewed?

A modified version of the Virtual Café, within the existing Virtual City (Brown et al., 1998), will be used as the basis for initial user assessment. The VE is implemented using Superscape VRT and run on Pentium PC's or laptop computers. The Café is accessed by a user at a single terminal. The user can perform a number of different tasks in the café, including sitting at a table, ordering food from a menu, ordering and paying for drinks at the bar and using the bathroom facilities. Instructions to users within the café appear in pictorial,

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written and/or spoken format. Movement around the café is achieved with a joystick and interaction with objects in the VE (e.g. how much money to pay the waiter) is achieved with the mouse.

The Café was chosen because it represents a social environment. Although dynamic interaction between characters in the café is not available at the present time, the café offers potential for virtual social interaction and could allow the development and refinement of target social skills before work-related environments are produced. The Collaborative User Group may suggest awkward situations that could arise in a café environment. These could be incorporated into the VE so that the users can gain some practice at skills which they identify as particularly problematic.

3.3 How will the VE be reviewed?

The first stage of the project involves gaining feedback on design and usability from the Collaborative User Group. This process will take place over three separate sessions:

Session 1. Users will use and explore the Virtual Cafe. Their comments will be audiotaped and/or videotaped to show to the Research Team. The purpose of this session is to allow familiarisation with the VEs and to gauge general ideas about problems/design issues. Following this session, specific questions will be tailored to the comments of each group member to be expanded upon in Session 2.

Session 2. The users will be asked to review the same VE whilst sitting alongside the Research Team member from the NAS. This is so that any issues highlighted from the tapes of the first session can be targeted at the relevant points in the program. It is hoped that this method of individualised questioning will help to identify specific design issues that can be tackled before Session 3.

Session 3. Some of the design issues highlighted in Session 2 will be implemented so that the group can see how their comments contribute to the development of the VE. Group discussion will reveal whether the changes are satisfactory and meet expectations. The need for further modifications can also be discussed.

The following stage will be to begin formal assessments of the use of VEs by people with AS, using the Participant User Group. In the first instance, the same VE viewed by the Collaborative group will be presented to the participants and their performance videotaped for later analysis. Fundamental issues will be investigated such as can people with AS use and understand the VE sensibly? How do they behave (verbally and non-verbally) when using the VE? Is there something specific about VEs that makes them particularly easy/difficult for people with AS? To gain a clearer idea of how the technology is used by people with AS, their interactions with the technology will be compared to other groups of users, such as people with learning disabilities, and normally-developing adolescents. Additionally, participants with AS will be tested on a number of standardised assessments in order to see whether particular profiles of cognitive ability are predictive of performance in the VE.

3.4 What do we expect the users to comment upon?

People with AS are characterised by idiosyncratic likes/dislikes and obsessive interests as well as a tendency to focus on details, rather than the general picture (Frith, 1989). Consequently, there may be unexpected aspects of the VE that the users concentrate on. This may help us to decide which aspects of the environment might be too ‘attention grabbing’ for people with AS and, hence, need to be modified during VE development. Idiosyncratic interests aside, we might find general features of the VE which users suggest need modification. For example, users may comment upon design issues such as the format in which instructions are presented. Some users may prefer to hear the instructions spoken, whilst some may want to see them written on the screen. There may also be suggestions on input devices, whether they are easy/difficult to use, what improvements could be made etc. Similar comments from many individuals about certain features of the VE will provide a good indication that a particular design or interface issue needs to addressed.

3.5 What do we expect to find from the initial user trials?

At the end of the first year the expected outcome will be an understanding of the acceptability of VEs to adults and adolescents with AS. In particular, the issues that need to be defined are:

(1) interface suitability for the target users (e.g. input devices and appropriate display media). Informal comments from the Collaborative User group and formal observations from the Participant User Group will help us to produce a VE that is tailored to the specific needs of people with AS.

(2) appropriate features of VE design (e.g. content, layout, use of text, frequency and type of instructions). Although it is hoped that there will be some agreement about certain design issues, an important point to keep in mind is that certain aspects of the environment should be amenable to individualisation. That is,

there should be choices built into the VE (e.g. the use of text and/or speech for giving instructions) which the user can adapt to suit their own needs.

(3) utility of the VE as an educational tool (e.g. efficacy of the tool in terms of measurable changes in participant performance). Results from the formal assessments of the Participant User Group will enlighten us as to whether significant improvements in knowledge or skill gains can be achieved through the use of VEs.

3.6 How will the project develop after the first year?

Years two and three will continue and expand the program of VE development and testing. The Collaborative User Group will be involved throughout the process to review new environments and provide feedback about modifications and improvements. Formal assessments within the Participant User Group will follow-on from the input of the Collaborative group, in order to test the usefulness, feasibility and acceptability of VEs and CVEs for people with AS. One of the main considerations will be the development of a usable end-product that will afford real benefits for users in terms of developing and practicing specific social skills. The development of ideas and knowledge gained through the research process will ultimately enable us to generate a product that can be accessed by as many users as possible. The Internet provides the perfect opportunity for allowing users to interact in a virtual world, which is developed and controlled by, and individualised and tailored to, people with AS.

4. CONCLUSIONS

People with AS are in need of a training environment that can help them cope with the demands of social interaction. Virtual reality offers a stable and predictable environment in which interaction can take place without the anxiety-inducing plethora of non-verbal and verbal information that characterises social interactions. Consequently, the role of Virtual Reality in the remediation of social difficulties for people with AS could be extremely powerful. The value of the approach taken by the *AS Interactive* project is that the insight and experiences of users with AS will have a direct impact on the development and design of new VEs for other people with AS. In this way, it is hoped that the end-product will be of significant benefit to users because the very specific needs of people with AS will have been investigated and addressed from the outset. Only if we listen to the voices of the people that we are trying to help can we gain the knowledge necessary to translate information into action.

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Session VII. Assessment & Rehabilitation

Chair: Luigi Pugnetti

Applications of virtual reality for the assessment and treatment of topographical disorientation: a project

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ABSTRACT

The traditional tools afforded by neuropsychology have proved to be of considerable service not only for the description of the clinical course of illnesses, but also for their nosographic and diagnostic contextualization. Virtual reality technology appears to be able to take on a valued rôle within the variety of diagnostic tools that are necessary for an adequate assessment of impairments of executive function. Development of diagnostic tools based on virtual reality may be cost-effective, particularly with respect to old but still widely used paper-and-pencil tests. The aim of the project presented in this paper is the creation and validation of various VEs to improve the assessment and rehabilitation of topographical disorientation, a disease present in various cerebral pathologies.

1. INTRODUCTION

Topographical orientation disorders may be the expression of memory or attention deficits, unilateral spatial neglect, or elementary visuo-perceptive disorders. In a minority of cases, topographical disorientation presents as an isolated disorder and is the expression of a focal brain lesion (Cammalleri *et al.*, 1996; Nichelli, 1996). Some authors observe that topographical disorientation may also be seen in a variety of brain disorders, including developmental conditions (Fine et al, 1980), progressive demential diseases (Passini et al., 1995), epilepsy and traumatic brain injuries (Whiteley & Warrington, 1978).

Most information regarding neuro-anathomic correlates have been reports of more than 200 patients developing relatively selective defects in topographical functioning following the onset of focal lesions due to stroke, penetrating missile wounds, or surgical resection for treatment of epilepsy or tumour (Barrash, 1998).

Most environmental representation is predicated upon the ability to recognise specific locations where navigational decisions are executed (Aguirre & D'Esposito, 1999). This perceptual ability is termed *landmark* (or place) recognition and is thought to be the first "topographic" ability acquired in developing infants (Piaget et al., 1960). Subjects improve in their ability to successfully identify environmental features with developmental age.

Route knowledge describes the information that encodes a sequential record of steps that lead from a starting point, through landmarks and finally to a destination. This representation is essentially linear, in that each landmark is coupled to a given instruction (i.e. go right at the bank), that leads to another landmark and another instruction, repeated until the goal is reached. While more information can be stored along with a learned route, there is evidence that subjects often encode only the minimal representation that is necessary (Byrne, 1982).

Descriptions of route learning also emphasise its grounding in an *egocentric* co-ordinate frame. Egocentric (or body-centred) space is the domain of spatial concepts such as left and right. Orientation is maintained within a learned route by representing egocentric position with respective landmarks (i.e. pass to the left of supermarket, then turn right).

Whereas route-learning is conducted within egocentric space, map-like representations are located within the domain of *exocentric* space, in which spatial relations between objects within the environment, including those observed, are emphasised (Taylor & Tversky, 1992). A developmental dissociation between egocentric and exocentric spatial representation has been demonstrated in a series of experiments indicating that these two co-ordinate frame representations are utilised by adult subjects (Acredolo, 1977). In order to generate a representation of exocentric space, exocentric spatial decisions must be combined with an integrated measure of one's motion in the environment. Drawing on recent research it appears that topographical disorientation is not a unitary construct but rather that it dissociates into several sub-types, depending on the underlying cognitive and perceptual processes that have been compromised.

The literature suggests that two different specific mechanisms may lie at the origin of the topographical orientation disorder; according to some authors (Paterson & Zangwill, 1945; De Renzi, 1982a), it is possible to distinguish a *topographical agnosia* and a *topographical amnesia.*

In *topographical agnosia* the patient is unable to recognise the characteristic elements of places that ought to be known to him. It is hypothesised (Thorndyke & Hayes, 1982; Kosslyn, 1990) that the deficit is due to a failure to analyse the specific aspects of visual stimuli (the "what" system; Ungerleider & Mishkin, 1982); the capacity to re-visualise mentally, refer verbally and sketch out the path that ought to be taken to go from one place to another remains, instead, intact.

Topographical amnesia is the condition in which the conspicuous points of the environment evoke a sense of familiarity and are easily recognised without, however, the subject being able to assign a spatial value to these points. According to the authors cited above, the deficit is due to the lack of functioning of the process responsible for identifying the spatial relationships between elements that are expressible according to topological notions of the type below/above, at the end of ..., on the right of ..., etc. (the "where" system; Ungerleider & Mishkin, 1982).

The anatomical correlates of the two systems involved in perceptive processing of the visual and spatial components ("what" and "where" systems) have been identified in two distinct cortical pathways, the first of which starts from the retina, passes through the lateral geniculate body, and proceeds up to the level of the occipito-temporal associative area (ventral pathway – "what" system), whilst the second terminates in the occipito-parietal associative area (dorsal pathway – "where" system) (see also Aguirre & D'Esposito, 1997).

While most authors agree that the posterior right hemisphere (cortical and subcortical) is involved, a variety of sites therein have been implicated, for example, posteromedial regions (Landis et al., 1986), the posterior parietal and adjacent lateral occipital and temporal cortices (De Renzi, 1982), the right paraippocampal gyrus (Habib & Sirigu, 1987), the posterior limb of the right internal capsule with secondary hypoperfusion in the right parietal region (Hublet & Demeurisse, 1992), the anterior commissure, right foramen of Monro, right fornix (Botez-Marquard & Botex, 1992), and the splenium of the corpus callosum (Bottini et al., 1990).

The cases of spatial disorientation present in the literature indicate an anatomical-functional correlation prevalently at the level of the right hemisphere, even though a bilateral involvement is not excluded (Goeffry *et al.*, 1997).

2. VIRTUAL REALITY IN THE ASSESSMENT AND TREATMENT OF THE TOPOGRAPHICAL ORIENTATION DISORDER

In the field of clinical neuro-psychology, virtual reality will probably change some of the diagnostic procedures that, decades after their introduction, are still used (Pugnetti et al., 1998).

Starting from the traditional tools afforded by neuropsychology, which have proved to be of considerable service not only for the description of the clinical course of illnesses, but also for their nosographic and diagnostic contextualization, the aid of virtual reality proves to be of major interest both as a complementary tool and to increase the possibilities of management of the patients from a rehabilitative point of view (Rizzo *et al.*, 1997).

The *immersion in the image* enabled by VR makes it possible to re-propose to the subject the "natural" features of the environment in which he lives and acts *as if* they were real. Recent research shown that training in virtual environments is comparable to training in the real world (Koh et al., 1999).

In particular, with reference to the assessment and treatment of topographical disorientation, virtual reality offers new possibilities to the clinician:

a) *Controlling and manipulating in a precise and objective manner the presentation to the subject of different variables that are implicated in the subject's capacity to orient himself topographically.*

On account of their intrinsic characteristics (for example, abstractness of the task) traditional pencil-and-paper tests are not able to assess the subject's orientation skills directly "*in vivo*". The tests proposed using virtual reality enable the subject to place himself in a "familiar" environment and to understand the task more easily. It is hypothesised that the direct connection between the nature of the task and the skills necessary for carrying it out may, on the one hand, increase diagnostic accuracy and, on the other hand, increase the subject's compliance to the assessment process.

b) *Using for assessment and rehabilitation a tool that reflects the life situations that are indispensable for the autonomy of the person.*

Current research conducted in a neuropsychology and rehabilitation setting suggests the importance of studying the topographical orientation disorder in view of the direct repercussions on the autonomy of the person. Of particular consideration is the presence of this deficit in various forms of brain disease and the consequent burden in terms of health assistance that this implies.

In particular, in a rehabilitation framework, the virtual environment presents itself as a highly ductile tool, in so far as it may be adapted, by the clinician, to the needs of the individual patient, of his deficits, and of his residual skills.

c) *Once the virtual environment has been created, the construction and use of immersion in this environment and the simulation of everyday situations, quickly and at a low cost.*

A complete and innovative assessment of the patient's topographical orientation capacities requires the performance of a number of tasks in the real environment. In the majority of cases, this procedure cannot be followed in so far as it is very costly in terms of time and the are additional problems for the patient admitted to a hospital structure.

The virtual environment makes it possible for the clinician to avail himself of all the advantages of a test that reproduces the features and stimulation typical of the natural environment, at the same time maintaining safety, objectiveness and serenity, both for the clinician and for the patient, whether from a psychological standpoint or from a health standpoint.

Virtual reality technology appears to be able to take on a valued rôle within the variety of diagnostic tools that are necessary for an adequate assessment of impairments of executive function. Development of diagnostic tools based on virtual reality may be cost-effective, particularly with respect to old but still widely used paper-and-pencil tests. If compared to other instruments which are less structured - such as in-the-field tests and direct naturalistic observation - virtual reality may not be as cost-effective, flexible and comprehensive, but may still be able to produce the kind of objective information that the former approaches generally lack (Pugnetti et al., 1998).

Our project will also use the theoretical model of 'wayfinding' in virtual environments, recently proposed by Chen and Stanney (1999). This model suggests that wayfinders generally commence by directly perceiving the environment or by working from a cognitive map. In terms of direct perception of the environment, landmark knowledge is acquired by directly viewing indirect representation such as photographs. In terms of cognitive mapping, procedure/route knowledge is acquired to through direct experience or through simulated experience and stored in memory. In addition, survey/configuration knowledge may be acquired from direct perception of the environment or from map use and also stored in memory.

3. DEVELOPMENT AND VALIDATION OF THE VIRTUAL ENVIRONMENT FOR THE ASSESSMENT OF TOPOGRAPHICAL ORIENTATION DISORDER

Compared to traditional pencil-and-paper neuropsychological tests, assessment via VR makes it possible to investigate in greater depth the functionality of the higher cognitive skills (attention, memory, planning) and to infer the degree of integrity of the underlying neural processes involved in the tasks of topographical orientation (perceptive analysis and identification of the shapes of objects – "what" component; perceptive analysis of the spatial relationships between the objects and execution of movements towards these objects – "where" component).

The virtual environment will be developed in such a way as to reproduce the peculiar characteristics of a typical quarter of a medium-sized town. Elements such as roads, streets, avenues will thus be used, in which reference targets and reference points will be placed, such as buildings, shops, offices, urban amenities, etc.

The validation of the assessment tool will be carried out on the results of the performance of 200 subjects who, on the basis of pencil-and-paper neuropsychological assessment, have proven to be in possession of unimpaired cognitive skills. The subjects' performance in VR will be compared with that obtained using traditional pencil-and-paper neuropsychological tests.

The development of the assessment tool suggests the creation of three sub-tests:

1. The first sub-test will be aimed at assessing *topographical agnosia* – the tool will assess the capacity of the subjects to recognise objects functioning as reference points inside the virtual environment.
2. The second sub-test will be aimed at assessing *topographical amnesia* – the tool will assess the capacity of the subjects to describe topographical relationships of which they have had experience within the virtual environment.
3. The third sub-test will be aimed at assessing *topographical orientation skill* – the tool will assess the capacity of the subjects to autonomously reach a target place within the virtual environment following a phase of getting to know the environment.

The assessment proposed for the subjects may thus be divided into four different interconnected tasks:

Type of task	***Variables assessed***
1 – *Getting to know the virtual environment*: the subject will be guided for a few minutes inside the virtual environment; he will be asked to observe the environment because, in a subsequent phase, he will be asked to move around autonomously inside it.	
2 – *Assessment of topographical agnosia*: the subject will be presented with certain target stimuli, some of which coincide with the reference points of the virtual environment which the subject has had the opportunity to encounter in task 1; other target stimuli will be new. The test will assess recognition.	Number of mistakes made by the subject
3 – *Assessment of topographical amnesia*: the subject will be asked to recognise spatial relationships (below/above, at the end of ..., on the right of ..., etc.) existing between some stimuli that he has encountered in task 1.	Number of mistakes made by the subject
4 – *Assessment of orientation skill*: the subject will be asked to reach a target stimulus inside the virtual environment in the shortest time possible and taking the shortest path.	Time taken to complete the task Distance covered Number of mistakes (compared to the shortest path) Target reached/not reached

The validation of the virtual environment for the assessment of the topographical orientation disorder will foresee the following actions:

1. Choice of the subjects that will be included in the validation study according to one basic criterion. The subjects must have achieved scores within the norm at a neuropsychological assessment in which, after a general assessment (Mini Mental State Examination - MMSE), the following areas will be further investigated: capacities of memory (Wechsler Memory Scale-Revised, Corsi Test, Verbal Span); capacities of attention (Attention matrices, Toulouse Test); and visuo-spatial skills (Cancellation of Gauthier bells, Benton Visual Retention Test, Elithorn Test);
2. Test on the 200 normal subjects;
3. Analysis of the psychometric characteristics of the tool.

4. DEVELOPMENT AND STUDY OF THE EFFECTIVENESS OF THE VIRTUAL ENVIRONMENT FOR THE REHABILITATION OF SUBJECTS AFFECTED BY TOPOGRAPHICAL ORIENTATION DISORDER

The virtual environment with which the subjects will interact in the course of rehabilitation will be organised hierarchically with respect to the difficulty of the tasks that will be proposed and will make precise reference to the theoretical cognitive model of the topographical orientation disorder.

Each rehabilitation treatment will focus on the specific areas of strength and weakness of each individual patient in terms of topographical orientation skill. The virtual town within which the subject will move around and perform specific tasks envisaged by the rehabilitation protocol will constitute the basic tool for:

a) re-training the patient in the specific cognitive functions that are deficient with respect to the task;
b) overcoming the deficit through the creation of compensatory mechanisms;
c) implementing alternative strategies for dealing with the orientation deficit.

The tasks proposed will tend to be moulded to the everyday tasks that the subject is normally used to performing.

The main aim is the development of a virtual environment which:

- is a reproduction of the peculiar characteristics of a typical quarter of a medium-sized town; elements such as roads, streets, avenues will thus be used, in which reference targets and reference points will be placed, such as buildings, shops, offices, urban amenities, etc.; and
- envisages the use of tasks organised in a hierarchical fashion as regards their difficulty and which reflect the theoretical model of the topographical orientation disorder.

In the creation of the virtual environment, which will form the basis of the cognitive rehabilitation of subjects affected by topographical orientation disorder, particular attention will be paid to the choice of:

a) types of target stimuli (e.g., bank, post office, pharmacy, food stores, etc.), so that they reflect reality faithfully;
b) tasks that have a particular interest for the subject and his autonomy, thus reflecting his day-to-day reality – the aim is to find tasks that motivate the subject to perform and that are meaningful for personal autonomy);
c) difficulty of the tasks – the tool will be built in such a way as to present a gradually increasing complexity of the stimuli proposed to the subject; and
d) tasks that are consistent with the theoretical reference model.

The first trial will be conducted to verify the effectiveness of the tool and for the subsequent definition of:

- the virtual environment created as a basis for cognitive rehabilitation of subjects affected by topographical orientation disorder; and
- the rehabilitation protocol used.

4.1 Recruitment of subjects

All the subjects will undergo a neuropsychological assessment (pencil-and-paper test). Criteria for exclusion are: a score of less than 16 at the MMSE; serious aphasia; serious behaviour disorders; serious reduction in hearing or eyesight.

The sample will include 10 subjects who have presented topographical orientation deficits in the assessment phase in the virtual environment and who will take part in the effectiveness study.

4.2 Methodology

According to a randomisation procedure, the subjects will be assigned to the clinical-rehabilitation group (5 subjects) or to the control group (5 subjects).

4.3 *Rehabilitative intervention*

The subjects assigned to the clinical group will undergo 15 cognitive-rehabilitation sessions with a three-weekly frequency, each session having a duration of 40–50 minutes (15–25 minutes in the virtual environment).

In the rehabilitation phase, the same tasks (stimuli) will be proposed to all the subjects in the same sequence. Each patient will be stimulated to perform the task successfully following cognitive rehabilitation techniques that take into account his deficits and his residual skills.

The rehabilitation protocol will contemplate the use of the virtual environment according to a growing complexity (the same for all subjects), with the aim of gradually retraining the patient to overcome his deficit, where possible, or propose to him compensatory strategies or aids that take into account his residual faculties and his specific deficits.

4.4 Assessment of effectiveness

The effectiveness of cognitive rehabilitation with the use of virtual reality will be assessed by comparing the results obtained at neuropsychological assessment (pencil-and-paper tools, assessment in VR) before and after treatment (within one week before start of treatment and one week after end of treatment) and by a person other than the rehabilitator.

The analysis of the results will be carried out both within each individual group (whether clinical or control) and by comparing the two groups.

5. CONCLUSIONS

Virtual reality technology could have a strong impact on neuropsychological assessment and rehabilitation. The key characteristic of VEs is the high level of control of the interaction with the tool without the constraints usually found in computer systems. VEs are highly flexible and programmable. They enable the therapist to present a wide variety of controlled stimuli and to measure and monitor a wide variety of responses made by the user.

However, at this stage, a number of obstacles exist which have impeded the development of active research specifically testing persons with cognitive impairments. These obstacles include problems with acquiring funding for an almost untested new treatment modality, the lack of reference standards, the non-interoperability of the VR systems and, last but not least, the relative lack of familiarity with the technology of researchers working in these areas.

The aim of this project is the creation and validation of various VEs to improve the assessment and rehabilitation of topographical disorientation, a disease present in various cerebral pathologies.

Our project will also use the theoretical model of wayfinding in virtual environments, recently proposed by Chen and Stanney (1999). This model suggests that wayfinders generally commence by directly perceiving the environment or working from a cognitive map. In terms of direct perception of the environment, landmark knowledge is acquired by directly viewing indirect representation such as photographs. In terms of cognitive mapping, procedure/route knowledge is acquired to through direct experience or through simulated experience and stored in memory. In addition, survey/configuration knowledge may be acquired from direct perception of the environment or from map use and also stored in memory. The result of the integration of these three types of spatial knowledge is a cognitive map. Beyond spatial knowledge, cognitive maps may also contain wayfinding decision and plans.

Our hypothesis is that the study of spatial orientation through specific tasks, both in a normal sample and in subjects affected by topographical disorientation, can bring greater comprehension and validation of cognitive models of spatial orientation than that currently available.

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Virtual Reality and Stroke Assessment: Therapists' Perspectives

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ABSTRACT

Involving users in the early stages of design has implications for the development, usability, acceptance and implementation of new computer systems. A project exploring the practical application of virtual reality to stroke assessment recently commenced at the University of Nottingham, with an emphasis on user centred design. A consortium of stroke therapists and researchers has guided the direction of the project through their involvement at the early planning stage. The consortium has provided broad guidelines for design, potential applications and identified barriers to this technology being routinely used in stroke assessment. This paper describes the process of introducing stroke therapists to virtual reality and presents their views on how it could be applied to stroke assessment.

1. INTRODUCTION

Stroke is a general term used to describe a condition in which the patient has suffered a sudden and usually debilitating traumatic brain injury, resulting in focal neurological deficit. Subsequent impairments which may be evident following a stroke include reduced cognitive functioning, memory loss, visual neglect, and disorders in self-awareness. A variety of assessment tests are available which are used to identify remaining functioning abilities and appropriate methods of rehabilitation. The most common assessment batteries used in the UK are the Rivermead Assessment Battery (RPAB) and the Chessington Occupational Therapy Neurological Assessment Battery (COTNAB). These contain a variety of drawing and picture-recognition tests which are used to determine what the patient can see in the visual field, how they interpret this information, their level of object recognition and memory functioning.

Although these tests are effective and have the benefit of standardised measures, it has been suggested that virtual environments might be useful for assessment and rehabilitation of cognitive functioning (Pugnetti et al, 1995; Rose et al., 1996; Rizzo and Buckwalter, 1997; Riva, 1998), improving spatial skills (Stanton et al., 1997) and learning and practice of everyday life skills (Christiansen et al., 1988; Brown et al., 1999). A project recently commenced at the University of Nottingham to explore the potential for using virtual environments (VEs) in stroke assessment. The project aim is to design and evaluate VEs that could support the goals of currently used assessment strategies, with a focus on practical implementation through user centred design. This work forms the basis of a part-time PhD begun in October 1999 by the first author.

The introduction of the virtual environment as a medium for the assessment of the stroke patient requires careful consideration of a wide range of complex user issues. In particular, implementing this technology within a programme of stroke rehabilitation as part of the routine assessment procedure has broad implications for both the patient and for the healthcare professional. The imposition of virtual reality technology might cause a negative response from healthcare workers who may feel threatened by any change to existing procedures, particularly if the current procedures are considered to be adequate to the task. Garside (1998) reports that some individuals within an organisation are frequently resistant to and resentful of imposed change. We were therefore interested to find out how occupational therapists (OTs) who work with stroke patients would regard virtual reality technology as a potential medium for conducting the tests which would be used as part of their routine assessment. The cutting edge of VR technology in assessment of brain injury contrasts sharply with the humanistic nature of occupational therapy. One of our concerns is that although academic research has demonstrated practical benefits of VR technology in assessment and rehabilitation following traumatic brain injury (Riva 1998; Rose et al 1997), the practical implementation of this technology might be resisted. Without the involvement of the users of this technology during the design phase, their needs and concerns might be overlooked; this could make our project impractical and its results unusable (Norman 1986).

A seminar was held at which occupational therapists were invited to experience virtual environments and to offer their perspectives on the application of VR to stroke assessment. Issues relating to the design and implementation of VEs for assessment were discussed. Encouragingly, there was a very positive response from the OTs who attended, despite most having no previous inexperience of virtual reality. Some concerns were raised which are discussed later. The outcome of the seminar, however, has been the formation of a consortium of occupational therapists who are interested in becoming involved with all aspects of design, evaluation and patient trials. The consortium has contributed to the initial planning and design of virtual environments through their discussion of user needs and will be consulted during redesign and evaluation throughout the project life-cycle.

2. THE SEMINAR

2.1 Overview

A seminar was held at Nottingham to which occupational therapists who work with stroke patients were invited. A list was obtained from Social Services of every community-based occupational therapist in the Nottinghamshire region who works with stroke patients. A list was also obtained of OTs in hospital-based stroke care throughout Nottinghamshire. The target sample was selected because it was a convenient and accessible population, although it is envisaged that future studies will draw from wider sources. A total of twenty-two individuals attended the seminar. Although invitations had initially been restricted to Occupational Therapists involved in care of the stroke patient, some OT departments had, because of workload, delegated colleagues to attend.

The aims of the seminar were:

- To inform healthcare professionals involved with stroke rehabilitation about the project.
- To explore currently used assessment strategies and identify areas which could be improved upon.
- To involve health professionals in discussions about user related issues.
- To discuss the potential of virtual reality technology to provide reliable and valid data.
- To identify an initial programme of VR development and evaluation.

In order for dialogue to commence it was essential that the OTs had some understanding of the nature of virtual reality, it's limitations and potential. It was also felt that their understanding of patient's needs as primary users of this technology would be improved by direct experience of a variety of virtual environments. The environments selected have all been used to support learning and/or training of real world activities, some of these have been applied in special needs education. Having gained this experience, it was envisaged that the OTs would be able to make informed decisions about user issues, barriers to implementation and the direction in which they felt the project should progress. This would be achieved by appraising assessment strategies currently used at the outset of and during rehabilitation and attempting to identify features which might be improved upon. It was hoped that a reasonable level of consensus would emerge and that a number of individual OTs would identify themselves as willing to contribute further to the project

2.2 Demonstrations

The seminar was timed to last for two hours. A short presentation was given during which some of the terminology and concepts used in virtual reality and virtual environments were explained. Delegates were then shown four virtual environments, all developed by VIRART, which they were encouraged to experience first hand. Although the virtual environments differed in their complexity and operation there was a planned progression through the demonstrations:

1. The Virtual Factory (Figure 1) is a realistic simulation of a manufacturing industrial environment. It has been designed to teach and assess health and safety issues in a manufacturing industry. The factory contains hazards that the user must identify and where appropriate rectify. The user navigates within an environment comprised of a large central factory area with a number of side rooms. This environment was selected because of its realism and focus on safety issues. Its simple, mouse-based navigational interface also makes it an ideal first encounter with VR (Cobb and Brown, 1997).
2. The Virtual City presents a wide variety of simulated activities, including acquiring items on a shopping list (Figure 2), using a bus and navigating around streets. It is a dynamic city with traffic moving, people

walking, shops into which one can walk and road crossings which must be operated correctly. It offers the opportunity for a wide range of different users needs issues to be addressed within one environment. The quality of visual information is approximately the same as the factory however the size and complexity of the environment and the sequences of tasks required to function within it are greatly increased (Brown et al., 1999).

3. Virtual Lego (Figure 3) comprised of a kit of pieces which must be put together in the correct order to build a three-dimensional model of an off-road vehicle. It was demonstrated to show how spatial manipulation and sequential processing can be practised and assessed in a virtual environment. The complexity of sequencing of tasks is approximately similar to those in the virtual city, however in this environment objects can be manipulated and rotated using the mouse or other standard input device (D'Cruz, 1999).
4. The Tangible Interface is a device that is placed on top of a standard keyboard (Figure 4). It comprises of physical objects with the same feel and appearance of their functional real world counterparts. These include a coffee jar lid, a kettle switch, a spoon, a kettle and a carton of milk. On the screen, a virtual environment simulating a kitchen with virtual objects is displayed. Interacting with the physical objects causes activation of the virtual equivalent. For example unscrewing the coffee jar lid causes the lid in the VE to unscrew. Interactions with physical objects in the real world are mirrored in a safe virtual counterpart (Starmer, 2000). This environment and interface was shown to demonstrate that input need not be limited to mouse and keyboard, but can comprise special-purpose devices tuned to individual environments and patients.

Figure 1. *The Virtual Factory (Cobb and Brown, 1997)*

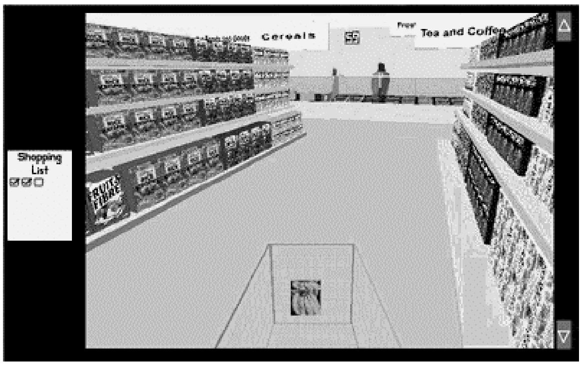


Figure 2. *The Virtual Supermarket (Brown et al., 1999)*

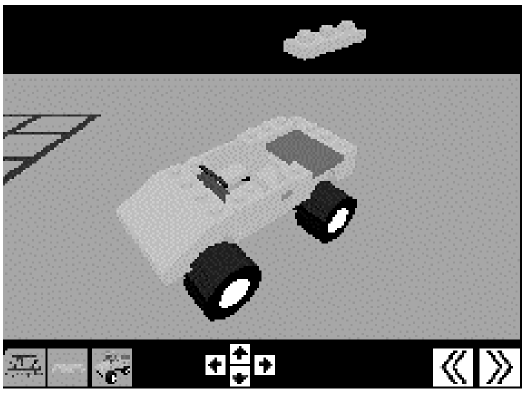


Figure 3. *Virtual Lego (D'Cruz, 1999)*

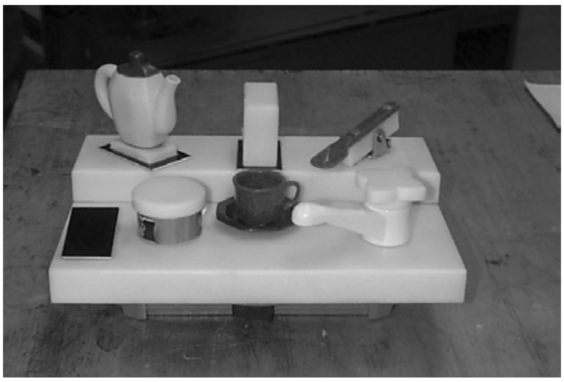


Figure 4. *Tangible interface to the Virtual Kitchen (Starmer, 2000)*

The delegates were divided into 4 groups, each of which spent roughly 10 minutes with each of the demonstrations outlined above. Each demonstration was supported by an individual, experienced demonstrator (two of the authors plus two other VIRART staff), who provided supporting information and explanations as required.

2.3 A Questionnaire

A questionnaire was devised to inform the project about current assessments used by the OTs during stroke rehabilitation and to ascertain therapists perspectives on the use of VR. Time to complete the questionnaire was provided during the seminar, immediately after the demonstrations. The questionnaire comprised five sections:

- *Your experiences with stroke patients* asked the therapists to indicate which aspects of stroke patient care they were involved and whether they were hospital or community based.
- *Your experience of virtual reality* asked if respondents had prior experience and what level.
- *Current Assessment Strategies* was designed to enquire about the tests used to assess the cognitive, perceptual and motor function following stroke.
- *The Patient and VR* listed twenty-five factors which might affect the design or use of a virtual environment system for stroke assessment and invited respondents to rate the importance of each on a five point scale, with the option to add comments.
- *Potential Applications of VR in Stroke Assessment and Rehabilitation* asked respondents to grade ten project ideas each based around a different aspect of assessment.

All of the delegates completed and returned the questionnaire.

2.4 Discussion Questions

The seminar closed with a discussion session, chaired by one of the authors and structured around three focus questions:

1. *What should influence the design of virtual reality systems for stroke assessment and rehabilitation?*
2. *At what stage in the rehabilitation process would virtual reality best be applied?*
3. *What are the barriers to this technology being used routinely in stroke assessment and rehabilitation?*

These questions were asked to initiate discussion and in the hope of eliciting a consensus of opinion on the route to best use of virtual reality technology in stroke assessment. Written notes were taken during the discussion session, which was also taped for future reference.

3. RESULTS

3.1 Demographics

The first two sections of the questionnaire show the context in which the main questions were asked. Half of those present were hospital-based occupational therapists, a further five were community-based OTs. Of those remaining, three were nurses/physiotherapists engaged in Health Care of the Elderly, while the final three were engaged in other duties within the hospital. Only two OTs claimed to have had any experience of VR prior to the seminars, one in the context of online shopping, the other in the context of 3D computer games.

3.2 Current Assessment Strategies

The questionnaire invited respondents to list and comment upon the techniques they currently use in the assessment of a variety of abilities and impairments, namely: a) recall of objects, b) recognition of objects, c) navigation around environments, d) spatial awareness, e) physical mobility, f) visual field defects, g) attention deficits, h) body image disturbance and i) sequencing tasks. Results are shown in Table 1, where numbers represent number of respondents using a particular method to assess a particular area.

Table 1.

Assessment Technique	Applied To								
	a	b	c	d	e	f	g	h	i
MEAMS	2	1							
Rivermead	2	1	1	3	1		1	2	
COTNAB	1	1		1		1		1	
Rey						2	2		
Practical	5	4	5	4	5	2	3	4	4

As one would expect, the Rivermead (Whiting et al 1985) and COTNAB tests are commonly used. Also employed is the Middlesex Elderly Assessment of Mental State (Thames Valley 1989), based upon a book of picture cards. Used with a similar frequency in our sample, the Rey Figure Perceptual Screen assesses the ability of a patient to reproduce a complex abstract line figure, testing the extent of disruption of the field of vision. The most striking feature of Table 1, however, is that under each assessment category at least half the respondents prefer practical tests based upon real physical objects over batteries of more abstract, standardised tests. This preference for real objects was also expressed in respondents' criticisms of currently available methods. Other comments expressed wishes for assessment tasks that consume less of the therapist's time, are more closely linked to treatment and can be modified to provide different levels of difficulty for different patients.

3.3 The Patient and VR

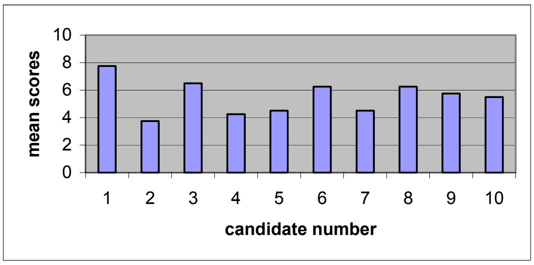
This section of the questionnaire was in two parts. In the first, respondents were presented with a list of eight patient features and asked to assess the weight they would give to each when deciding whether or not the use of a given VE-based assessment tool was appropriate. Space limitations preclude a detailed analysis of the data generated, suffice it to say that patients' age, motivation and severity of stroke were considered important features, as was any risk of side effects. Patient anxiety (due to stroke) was considered important, but somewhat less of an issue. Gender, physical mobility and prior experience of computer technology were generally considered not very important.

The second section sought opinion on factors that might affect the design and practical application of the technology. Ease of use by both therapist and patient was rated very highly, as was realism in the appearance and behaviour of virtual objects and the ability for therapists to set tasks at different levels of difficulty. The ability to manipulate virtual objects was also considered important, but secondary. This may be because of the potential for relearning sequences of operations provided by simpler, non-manipulative environments. The ability of the system to provide quantitative data was similarly rated important. Opinion was split on the question of simple vs. complex environments, perhaps because of a perceived trade-off between realism and usability. The most even response, however, was generated by the suggestion that virtual environments should only be used under supervision.

3.4 Potential Applications of VR in Stroke Assessment and Rehabilitation

Ten potential project areas were devised, based upon the aims and objectives of the currently used assessments. These were: 1) motor rehabilitation, 2) object recognition, 3) navigation, 4) assessing physical safety, 5) recall of object, 6) visual field deficits, 7) sequencing of tasks, 8) recognising body parts, 9) assessing neglected side and 10) ability to describe the function of objects. Respondents were asked to grade the suggested applications in order of preference. The mean ratings given are shown in Table 2, with lower scores indicating stronger preferences. Object recognition (3.75), safety (4.25), recalling objects (4.5) and performing sequences of operations (4.5), present themselves as the favoured applications of the sample of OTs questioned.

Table 2.



3.5 Therapists' Attitude to using VR

Finally, delegates were invited to express their personal response to the use of VR in clinical assessment. Six OTs reported positively that they would be interested in and/or would probably enjoy using VR. A further four expressed concerns over the level of staff training required and pointed out the need for evidence of effectiveness. Only two gave negative responses, preferring to use real world over virtual objects and tasks.

3.6 Discussion Questions

3.6.1 What should influence the design of virtual reality systems for stroke assessment and rehabilitation? As might be expected given the questionnaire responses, the general feeling was that the strength of VR technology lies in its ability to produce realistic, but safe and accessible, models of the physical world. The ability to create a realistic virtual environment in which the patient can perform purposeful tasks not possible in a real-world assessment/rehabilitation situation should therefore be a key design criterion. The assessment tasks should also be controllable. The provision of graded levels of difficulty was seen as highly desirable, both to suit the individual's ability and to respond to achieving targets. The task should also be able to be embedded in a wide range of scenarios to encourage transfer. It should be possible to monitor performance and progress. A good environment design would also allow the patient to work independently of the therapist, perhaps with support from other carers.

Controlling the environment raised some concern due to the differing physical abilities of these patients and it was suggested that a variety of input modes should be offered. These included touch screen, mouse, keyboard and other controls, their suitability would, however, depend upon the application and patient's physical ability. There was some feeling that the technology may not be appropriate during the acute initial phase.

3.6.2 *At what stage in the rehabilitation process would virtual reality best be applied?* There was a lower level of consensus in the group's response to this question than to either of the others. It was suggested that VE s could be used to support initial assessment in hospital, but might also find use during long term rehabilitation in both home and clinical environments. There are clearly a number of scenarios worth further investigation. Attention shifted during the discussion towards the interface between hospital and community. It was suggested that community-based OTs might take a laptop when visiting patients, supervising their actions in a VE tuned to their personal situation. Alternatively, patients might use VEs unsupervised, with the therapist reviewing progress during visits. The move towards more community-based care in the UK has prompted an interest in assessing independence; comments were frequently made about the difficulties of safety assessment and the potential of VR to provide a safe method of developing patients' ability to perform hazardous tasks. The need for realism was again raised several times.

3.6.3 *What are the barriers to this technology being used routinely in stroke assessment and rehabilitation?* Potential cost was identified early in the discussion, though the emphasis soon turned away from raw financial expense to the need to demonstrate clinical effectiveness. The current political climate stresses evidence-based practice, which requires outcome measures showing the benefit of a given treatment. That benefit may be indirect, improving the patient's self-esteem, for example. It was, however, suggested that other forms of computer-based rehabilitation have not been widely accepted because of a lack of evidence of transfer of training. Any successful system must also be quick to set up, easy to use and provide useful and usable feedback directly to the therapists.

4. DISCUSSION AND FUTURE WORK

The occupational therapists who attended the seminar were generally inexperienced in virtual reality prior to attending however their experiences with stroke patients have provided an insight into the issues and concerns which are important to them in the design and application of this technology. The attendance was not high but reasonable considering the source population invited. The actual numbers present meant that individuals were able to work in groups of five or six at each of the workstations. The trade-off was that for analysis purposes the questionnaires only provided a small sample size.

The use of VR to directly replace currently used assessments following a stroke was not pursued by the OTs. Emphasis was placed instead on the possibility of embedding assessment and rehabilitation strategies within realistic but controllable models of environments and (possibly hazardous) tasks which would be difficult to achieve in the real world. There would appear to be significant potential for the successful application of VR to stroke medicine in this way. Concerns were however raised that in order for this technology to be routinely used, in a climate of evidence-based practice, trials of virtual reality assessment tools would have to show a demonstrable improvement over current procedures. This will be the one of the challenges this project will have to meet.

As a follow-up to the initial seminar a meeting was held between the authors and a group of four consultants actively engaged in stroke research. Two of these have an occupational therapy background. The same virtual environments were demonstrated and the same discussion questions posed. The consultants were not, however, invited to fill in the questionnaire as a sample of four would be too small to yield any comparable results. It was interesting to find that the OT-based consultants independently focussed on safety assessment at the point of discharge between hospital/institutionalised care and community care as important. The consultant group also concentrated on the potential of VR to embed treatment strategies with realistic simulated environments rather than to simply mimic the currently available abstract test batteries. The consultant group stressed the individual differences expected between stroke patients even more strongly than the initial OT group. They suggested that initial research in this area might usefully take a case-based approach, working closely with a small number of patients rather than immediately attempting to identify generic techniques and solutions. The concept of enablement was introduced by one consultant and led to consideration of possibilities hitherto not discussed, such as increasing the quality of life by reducing frustrations such as communication problems and increasing patient participation in activities through collaborative interaction in a virtual environment. Language and speech difficulties were identified as a major source of anxiety and frustration amongst those patients who had made a good recovery. Further work in this direction is being initiated and will be the subject of a future report.

The results of the work described here have led us to the conclusion that ecological validity is among the most desirable attributes of stroke assessment and rehabilitation methods. Virtual reality may have the potential to address issues of object recognition, recall, navigation and sequencing tasks in simulated environments which can be controlled, to which levels of difficulty can be applied and from which objective data may be gathered. It is our intention to validate this statement through the development of stroke assessment and rehabilitation methods embedded in a virtual environment that encompasses these attributes. The current intention is to exploit the existing Virtual Supermarket (Figure 3), constructed as part of the Virtual City (Brown et al., 1999) and a faithful copy of a local store. This will provide the opportunities to make comparisons of patient assessment and attainment data between real and virtual environments and which will enable a range of assessments to be presented through recognisable and meaningful activity.

5. CONCLUSION

We have introduced virtual reality as a potential medium for delivering stroke assessment tools to the professionals who were previously unaware that this technology existed or that it could be used in this way. The interest generated has paved the way to the formation of a consortium of professionals who have expressed an interest in informing, guiding and evaluating all aspects of the project and this has also allowed us access to a potential patient base which will be used for future trials.

Possibly the most important issues concerning the use of VEs in stroke rehabilitation are the fidelity of the representation of the real world environment in a VE and the control interface used. This view is similar to that found in a study which examined occupational therapists' use and views of a virtual environment for making coffee (Davies et al., 1998). The therapists were able to complete the task in the virtual environment and it was concluded that VR could successfully be applied to patient training and rehabilitation although issues surrounding mental abstraction level, transfer of training and realistic interaction were identified. However, initial trials which required patients with traumatic brain injury to perform a meal preparation task within a virtual kitchen demonstrated adequate reliability in task performance with little or no evidence of adverse effects, despite the use of an HMD for viewing the virtual environment (Christiansen et al., 1998). This would suggest that it is feasible to apply virtual environment for life skills training in stroke patients.

Having invited healthcare professionals to offer their perspectives on virtual reality as a medium for stroke assessment, we feel that the next logical step in the user centred design process will be to identify patients themselves who are willing to participate in trials of VR technology. The immediate plans for this project are to commence a series of case-based trials, from which it is envisaged we will be able evaluate a variety of virtual environments and provide design guidelines which we hope will inform future projects of this nature.

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Using immersive virtual reality to test allocentric spatial memory impairment following unilateral temporal lobectomy

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ABSTRACT

Immersive virtual reality was used to investigate spatial memory in 17 right and 19 left unilateral temporal lobectomy patients and 18 control subjects. The subjects were administered a task consisting of a virtual room and table with radially arranged 'shells' on top. The subjects moved around the table and had to find a blue cube, which was under one of the shells. On subsequent searches, the cube moved to a new location and the subject had to find it whilst avoiding the previous location, and so on until all locations had been used. A selective deficit was observed in the right temporal lobectomy group only, linking allocentric memory to the function of the right hippocampal formation.

1. INTRODUCTION

Immersive virtual reality, in which the patient is physically able to move around in an imaginary environment, offers a promising new technique to explore spatial memory in a more realistic fashion, whilst maintaining experimental control. It also helps bridge the gap between non-human experimentation, where various forms of spatial mazes have been developed in order to help determine the neural basis for spatial memory. The immersive technique means that human analogues of the animal procedures can be developed for experimental use.

Both animal and human research point towards the hippocampal formation as being involved in spatial memory function. In animals, bilateral lesions of the hippocampus have been shown to result in deficits in spatial maze learning and single unit recording of cells in the hippocampi of rodents and monkeys demonstrate specific neurones that fire selectively according to the animal position or gaze direction in relation to spatial location (O'Keefe and Nadel, 1978; Rolls, 1996). These findings have led to the notion that the hippocampus may be involved in forming an allocentric representation of the environment, from which spatial memory is supported (O'Keefe and Nadel, 1978). This enables the animal to locate their position in space using external cues, irrespective of their bodily direction.

In humans large bilateral lesions of the hippocampus and surrounding temporal lobe regions produce global memory impairment. Unilateral lesions, however, result in modality specific or 'partial' amnesias depending on the side of lesion (Smith, 1989). This latter phenomenon has been established through investigating patients who have undergone unilateral neurosurgical treatment for intractable epilepsy. In order to remove a hippocampally based epileptic focus, a standard 'en bloc' operation involves taking out the anterior temporal lobe, the amygdala, the anterior two thirds of the hippocampus and sounding cortical tissue. If this is done in a language dominant left hemisphere it produces verbal memory impairment; if in the right side, there is impairment in visuospatial memory function.

The pattern of visuospatial memory deficit has been explored through experimental studies. One of the main approaches has been to show the patient a series of objects layed out in front of them and then ask them subsequently to place the object from memory. Patients with right unilateral temporal lobectomies are impaired on this task (Smith and Milner, 1989). Furthermore, there is evidence that the extent of this deficit dissociates from remembering the objects. A recent study by Nunn et al (1999) showed that object recall could be matched between patients and controls by varying the delay between presentation and memory test

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according to ability. Using these delays, there was still a pronounce spatial memory impairment in the right temporal lobectomy patients. The extent of this impairment was correlates with the amount of removal of the hippocampus.

The above type of task involves observing a static spatial array, with the possibility spatial location could be encoded in an egocentric sense, in relation to the bodily frame of reference. However, theories which link the hippocampus to spatial memory, incorporate the notion of an allocentric representation. A better test of previous theoretical approaches as applied to humans is to employ a task which is primarily allocentric in nature. A series of studies by Morris and his colleagues (summarised by Morris et al. 1999) have been conducted in this area. The first is a computerised task developed by Feigenbaum et al (1996). Here, a graphically represented turntable is presented on a computer screen. A number of spatial locations on the turntable were signified by black dots. The subject has to search these locations in turn, by touching each, with their response being recorded by a touch sensitive screen. When they touched the right one, the dot turned green. The correct location moved to another dot and the subject had to search again to find this new location, and so on until all the dots had been correct locations. In order to create an allocentric requirement, in between searches, the turntable would rotate such that the dots maintained the configuration in three dimensional, but not two dimensional space. Feigenbaum et al (1996) found that right unilateral temporal lobecotomy patients were selectively impaired on this task.

The Feigenbaum et al (1996) relied on rotation of the spatial array, rather than subject movement, in order to induce an allocentric memory requirement. An alternative task was designed by Abrahams et al (1997) in which a real table was used, with a circular layout of containers. The experimenter would place some objects in some of the containers and then ask the subject to move round the table. They would then have to select the containers that had objects in them and also determine which objects had been placed in containers out of a larger sample. This task showed a selective impairment in right temporal lobectomy patients only, but with memory for the objects impaired in both left and right operated patients. Abrahams et al (1997, 1999) also tested patients who had selective unilateral damage to the hippocampus, finding impairment in only those with right lesions. Additionally, the spatial memory impairment was related to the amount of hippocampal damage as measured using structural magnetic resonance imaging. This contrasted with the finding that the amount of object memory impairment was related to the extent of reduction in temporal lobe volume, but not the hippocampus.

The Abrahams et al (1997; 1999) studies support the link between allocentric spatial memory and right hippocampal functioning. Furthermore, spatial memory tasks in general have consistently shown impairment associated with right temporal lobe damage. A criticism of these tasks is that they lack the experimental control needed to determine the specific mental processes involved in solving the task. For example, in the Abrahams et al (1997; 1999) study the patient could use extraneous room cues and associate these with specific locations, without recourse to spatial memory. To some extent this type of problem can be solved through darkening the room, but it is very difficult to rule out the use of visual cues in the environment completely. For this reason, Immersive Virtual Reality was adopted as means of providing complete control of the visual environment and at the same time developing a task which would involve whole bodily movement with corresponding visual mapping. A task was developed, termed the *Shell Task*, which consists of a virtual room which contains in the centre a virtual round 'table' (see Figure 1). Radially arranged on the table are up turned 'shells' The object of the task is walk round the table in order to inspect each shell in turn. When a the right shell has been selected, a blue cube appears on the table in front of the subject. The subject then has to search the remaining shells in order to find one that triggers the appearance of the blue cube (in the task the subjects are told that the blue cube is under the shell). Each time the cube is found it moves to a new location, never returning to a previously used one. The task finishes when the cube has moved to all the locations. The task is to search for these different locations, whilst avoiding going back to a previous one. This task, to our knowledge, the first immersive virtual reality test of spatial memory, has been applied to patients with unilateral temporal lobectomies to further explore the link between allocentric spatial memory and the right hippocampal formation.

2. METHOD

2.1 Subjects

36 unilateral temporal lobectomy patients were included in the study (17 right; 19 left), seen a minimum of six month post-operatively. They were matched approximately for age and National Adult Reading Test estimated IQ with a control group of 18 subjects (respectively: Age Left: mean = 38.6, S.D. = 7.9; Right: mean = 36.4, S.D. = 10.2; Controls: mean = 38.8, S.D. = 5.9; IQ Right: mean = 111.9, S.D. = 9.6; Left: Mean = 104.4, S.D. = 8.3; Controls: Mean = 115.0, S.D. = 5.9). The patients has a standard en bloc resection, with between 5.5 and 6.5 cm of the anterior temporal lobe removed, the amygdala and approximately the anterior two thirds of the hippocampus.

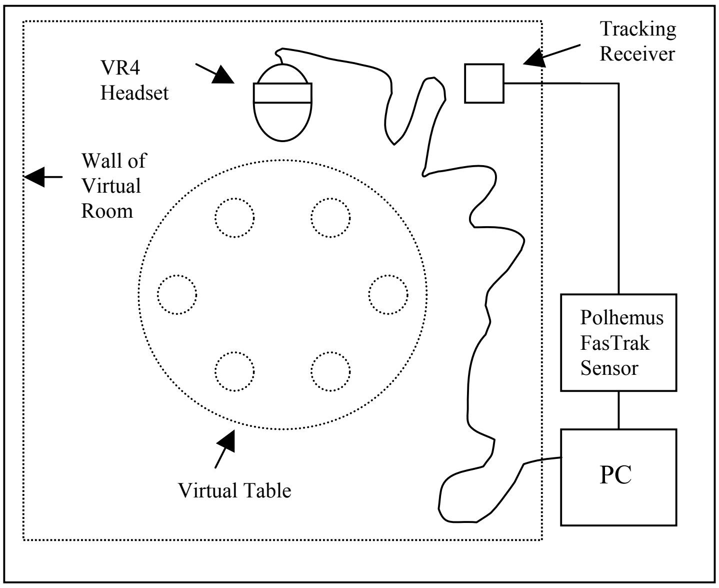

Figure 1. *The layout of the Shell Task.*

2.2 Virtual Reality Test

The World Tool Kit software package was used to construct the virtual environment, with the virtual room, table and shells (see Figure 1). A head mounted display (VR4 headset) projected the visual image to the subject and the position of the head was tracked using a Polhemus FasTrak Sensor system. This system tracks lateral, forward, backward and up and down movement of the head. The information is fed into the PC, with online processing of tracking data and image construction, which in turn changes the projected visual display.

2.3. Procedure

The procedure, termed the *Shell Task*, involves the subject standing in a room wearing the VR4 Headset. The subject stands in front of the Virtual Table (diameter 1.5m), facing the centre (see Figure 2). The Virtual Table is inside the Virtual Room (represented by dashed lines in Figure 1), which has 'bare' walls. The shells on the table are concave and coloured as indicated below, arranged radially. The subject has to walk around the Virtual Table and inspect the shells by 'looking under' them. In order to inspect a shell they walk in front of it and say the word 'lift.' This cues the experimenter to activate the removal of the shell using the PC keyboard. If the blue cube has been under the shell, it will then appear. If not, there is an empty space when the shell was placed. Following an inspection the shell returns to the original position.

The object is to search the shells until a blue cube is found. At this point it moves to a new location and the subject has to search again, and so on until all shells have had the blue cube under it. The subjects are instructed not to go back to shells where there has previously been a blue cube. Thus the design involves a series of searches to find the blue cube, a trial comprising the total set of searches.

In order to stop the subject using a simple search strategy of going round the table and inspecting each shell in turn, the following modification to the task was made. For each 'search' the subject is restricted to inspecting only half the shells. This is achieved by colour coding half of the shells green (those that can be inspected) and the other half red (those that can not be inspected). When a search is finished (a blue cube is found), the shells that are green and red will change. Allocation to green or red is arranged pseudorandomly, with the exception that the target shell is always green.

After practice trials, the subject is tested in a version of the task with four shells for four trials. Next they have a six shell version, for three trials.

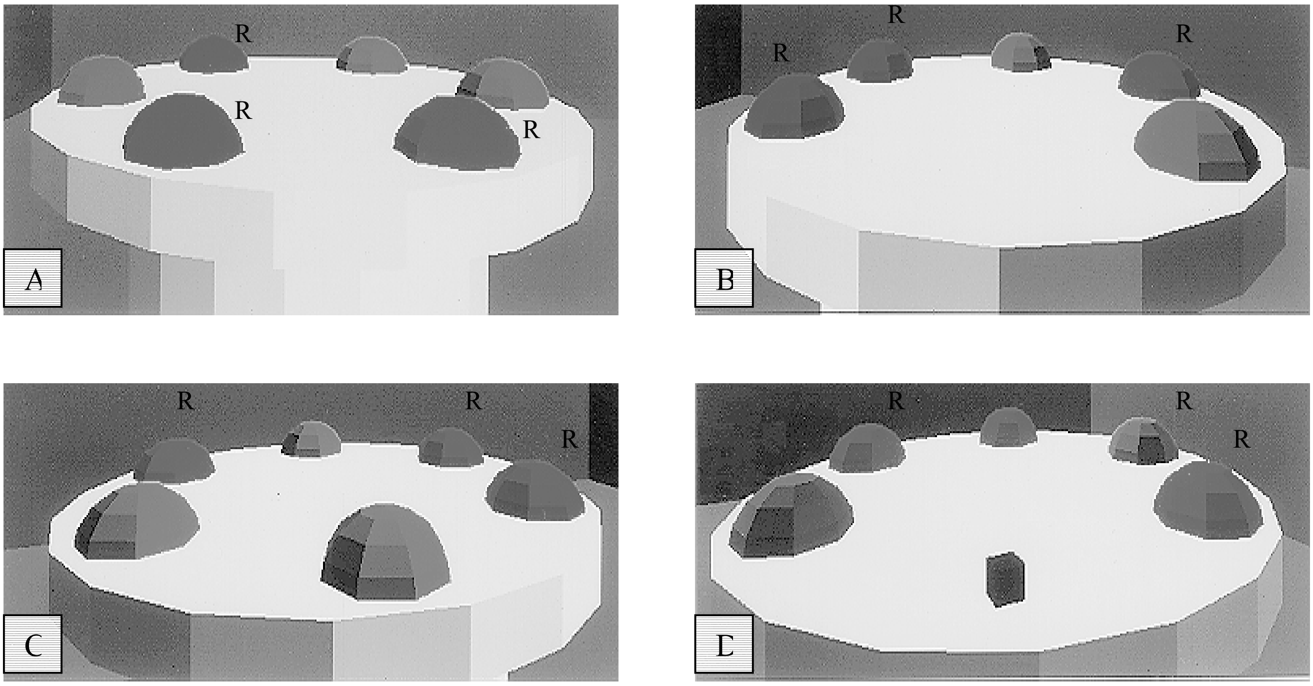

Figure 2. *A series of views during a search for a blue cube. In this black and white illustration the restricted (coloured red) shells are labelled 'R.' (A) shows the layout at the start of the search; (B) shows the viewpoint when the subject has moved round the table and has just inspected a shell to reveal no blue cube; (C) the subject has move to the right and is just about to inspect a shell; (D) the shell is lifted and the blue cube is found.*

3. RESULTS

The task generates two types of errors:

(1) *Within-Search* errors involve going back to a location that has been inspected previously within the same search. Here the errors were minimal (means for 6 shell trials: right TL = 0.00; left TL = 0.00; Controls = 0.02; means for 6 shell trials: right TL = 0.08; left TL = 0.08; Control = 0.07). No statistically differences were found between groups at either level.

(2) *Between-Search* errors involve selecting a shell that has had a cube underneath it on a previous search. The data are shown in Figure 3. For the forth trial with four shells (4D) was included in order to check that the subjects could follow the procedures, whilst minimising the memory load. The shell was always to the right on the one under which the blue cube had been found. The very low error rate in this condition confirmed the subjects in each group were following the instructions correctly. This trial was excluded from the subsequent analysis. With six shells, there was a clear deficit in the right TL, contrasting with no deficit in the left TL group. The performance of the subjects can be compared to chance levels of responding, as shown in the control panel of Figure 3.

The data were analysed using a two-way MANOVA with group (right TL; Left TL and Controls) as a between-subject factor and shell number (4 and 8) as a within-subject factor (collapsing across Trial A-C). There was a main effect of Group ($F(1,51) = 5.19$, $P < 0.001$) and shell number ($F(2,51) = 3.61$, $P < 0.01$), with a significant interaction between the two factors. A subsequent analysis showed that the groups differed with six, but not four shells. For six shells, an ANOVA showed a main effect of Group ($F(2,51) = 2.68$, $P < 0.01$), and the Least Squares Differences (LSD) showed the right TL to be significantly impaired in relation to controls, but with no other significant difference. In addition, these analysis were repeated with age and intelligence as covariate, but no difference in pattern was observed. Gender differences were explored using by repeating the main MANOVA with Gender (Male/Female) as an additional within-subject factor. No effect of Gender or interaction with the other factors was observed.

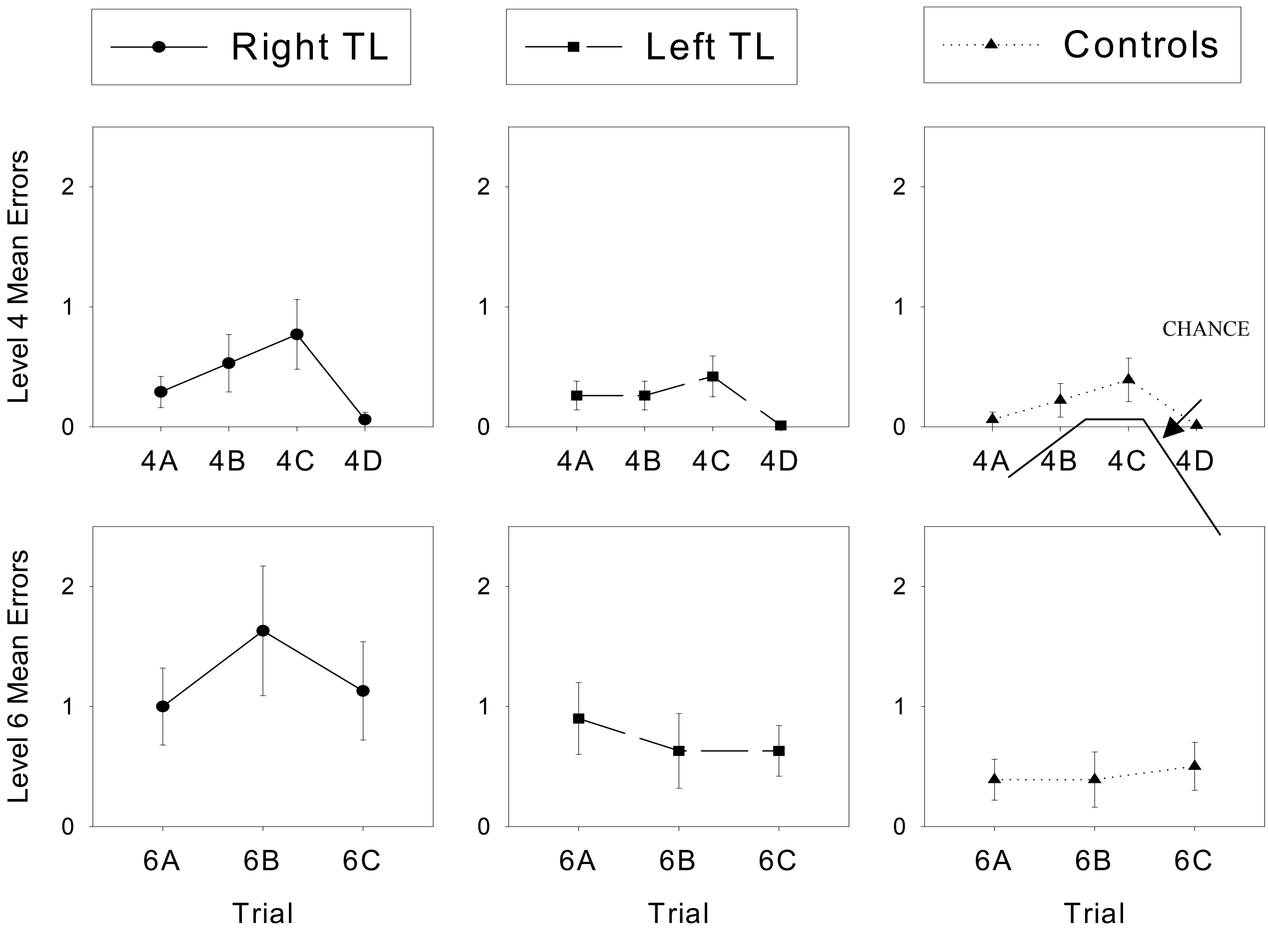

Figure 3. *The between search errors on the Shell task, with standard error bars. The figure shows the performance of the right and left temporal lobectomy groups versus controls with the different trials for the four and six shell level (respectively 4A to 4D and 6A to 6C). The number of errors assuming chance level of responding are given in the panel for the controls (see text for the manner in which chance was calculated.*

To illustrate movement performance, the trajectories of the subjects who completed the 6A trial using the same path up to the fifth search (n = 33) were classified by an independent who had no knowledge of what groups the subjects were in. On the basis of this, the subjects were divided into three categories: (A) those who were moving in a smooth and directed pattern; (B) those who showed some uncertainty in their movement and who would double back in their trajectory, and; (C) those with erratic movements. For category A there were 12 / 33 subject (7 controls; 7 left TL); For category B, 19 / 33 subjects (4 controls; 7 left TL and 11 right TL); For category C, 3 subjects (1 control; 1 right TL; 1 Left TL).

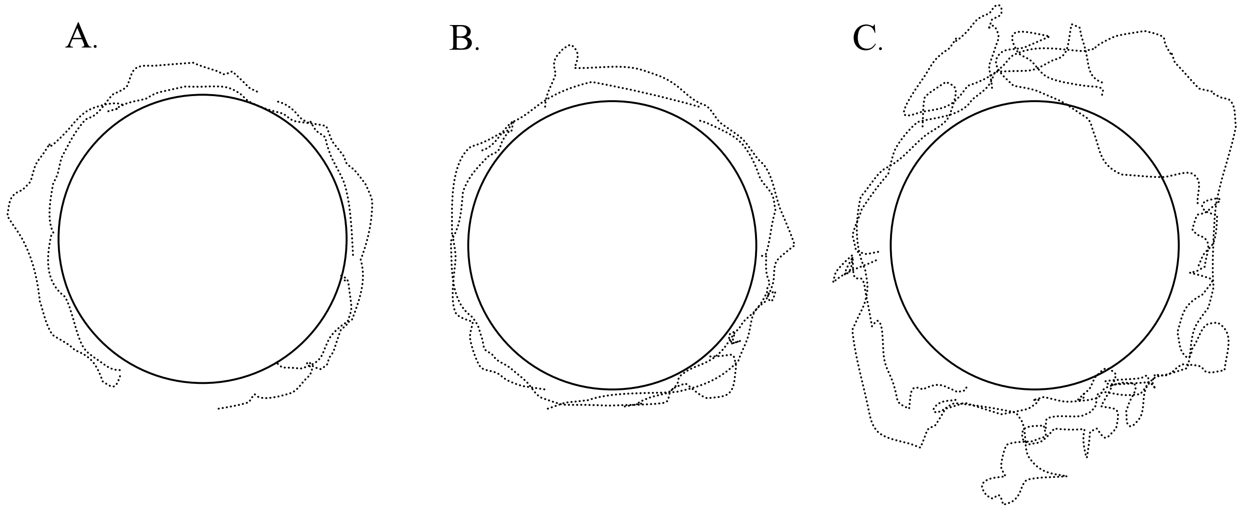

Figure 4. *Examples of the paths traced during a six shell problem. (A) is an example of a smooth and directed pattern. (B) shows doubling back or uncertainty in movements. (C) shows a highly erratic mo vement pattern.*

4. DISCUSSION

The study shows a clear spatial memory deficit in the right temporal lobectomy group, expressed in terms of the tendency to return to the previously successful shells. Very few errors were made in terms of returning to a previously successful location, suggesting that all groups were able to follow the task procedures. Additionally, errors were minimal on the forth trial with four shells, this being designed to check for procedure before going on to the more difficult level.

In relation to the application of immersive virtual reality to testing spatial memory in this group of patients, this study shows that the technology can be used effectively. A number of practical aspects of task design are considered here before discussing the implications of the results in terms of understand the neural basis of spatial memory. Firstly, the task was designed with a central table. This had the advantage of focusing the activity of the subject within a central space and the overall design enabled the task to stress the allocentric aspect of remembering location. However, we found that in order to complete the task, the subjects had to adopt the strategy of moving round the table whilst keeping their body facing the centre. Pilot studies had shown that, if they attempted to turn to the left or right and then rotate back towards the centre to view the table, this resulted in them being distracted from the memory aspects of the task. Consequently, we trained the subjects in terms of how to shuffle round the table in steady fashion, keeping the centre in view. We found that instructing the subject to make small movements ('small steps'), forwards or backwards, left or right, and then practising these movements enabled them to learning how to move correctly during the task. As indicated in the results section, a small proportion of subjects had difficulty with movement.

To truly exploit the advantages of immersive virtual reality, a much larger space would be needed, when the subject could walk around freely. This was not possible with the current technology, because the tracking mechanism had a limited range. Additionally, the ease of administration of the procedure was limited by the cable connecting the head mounted display to the computer. Technological innovations, combined with a larger workspace would substantially improve the scope for using immersive virtual reality to study spatial memory. A second aspect was the response mode used in the task. Originally, we had a glove mechanism such that the subject could 'touch' the shell in order to signal their inspection. Whilst this was a more elegant design aspect of the task, the effort the subject had to make in accurately touching the shells distracted them from attempting to remember the spatial locations. As a result, we adopted the simpler procedure of verbally instructing the experimenter whenever they wanted to select a shell. It is possible that immersive virtual reality could be eventually combined with speech reception to ease the interactive nature of clinical tests. More readily available in a reliable form, auditory feedback or instructional procedures to could enhance this type of test, using stereophonic presentation. For example, when inspecting a shell, an associated noise could reinforce the interactive nature of the task.

The size of deficit shown by the right TL patients, although numerically small, is substantial when compared to the chance levels of performance. This level of deficit appears to be greater than that recorded with conventional 'desk top' tasks, for example in the studies by Nunn et al. (1998; 1999), where it is possible that the configurations within a small array was sufficient to ameliorate the size of the deficit. Further investigations are needed to explore how much the impairment translates into problems with everyday navigation ability. Questionnaire evidence does highlight problems with navigating in unfamiliar environments in patients with the right TL (Miotto, Feigenbaum and Morris, 2000). The current Shell task may be closer to the 'real world' than conventional psychometric tests that measure spatial memory function.

Checking the ability of the patients to follow the task procedure was an important feature of the overall design of the study. This was done by measuring the number of times the patients returned to the same shell within a search, but using trial 4D, the 'check trial,' and also considering the paths made by the patients. Overall, the study showed that the patients could 'cope' with the procedures as well as the controls. This was to some extend predicted in this sample patients. Temporal lobe damage is not associated with spatial manipulation or producing motor activity. Unilateral lesions in the regions of the temporal lobe resected do not produce perceptual deficits that could interfere with performance. Furthermore, overlapping samples of unilateral temporal lobectomy patients from related studies show no impairment on a range of tests of (non mnemonic) visuospatial processing. The right TL group are unimpaired across a range of mental rotation and spatial manipulation tasks (Abrahams et al., 1997; Feigenbaum et al., 2000; Worsley et al., 2000). However, using the same procedures to study memory in patients with more widespread lesions may be problematic, for example, parietal or frontal lobe lesions affecting respectively spatial processing and coordination of motoric output.

The current procedure had the advantage that the total visual environment of the subject was controlled, in a manner that had not been achieved so far when exploring this type of memory in patients with selective impairment. In previous studies it has not been possible to eliminate the strategic use of associating spatial locations with proximal stimuli, including those relating to the testing room or, possibly, imperfections in the testing apparatus. To exploit this aspect, the walls of the virtual room were left blank. This procedure forces the subject to adopt two types of approaches. One is to keep track of the configuration of the shells and monitor a starting location, based purely on visual information. A second it to monitor movement around the table to compute and encode location, perhaps using proprioreceptive information. It is possible that both processes are used, and the current task does not enable us to disentangle these two possibilities. Certainly, there is evidence that monitoring of position relative to a fixed starting point (path integration) is impaired in patients with right TL, as shown in a recent study where patients were blindfolded and had to return to a starting point, after being led along two outward trajectories (Worsley et al., 2000).

A related issues is the neuronal distinction between visual processing, involving mainly pattern recognition, and encoding the spatial relations between objects. These types of processing are separated respectively in terms of perception, the visual analysis involving a neuronal pathway into the temporal lobe, and spatial processing the superior parietal region. Visual and spatial long-term memory has also been dissociated in patients with right temporal lobectomies (Nunn et al., 1998; 1999). The *Shell Task* has no distinctive object or environmental features, and hence relies more purely on spatial encoding. Thus the current study suggests that 'purely' spatial memory is impaired in the right TL patients, providing further support to the association between the hippocampal formation and spatial memory in humans.

6. CONCLUSIONS

In conclusion, an immersive visual reality system has been used to create a spatial memory test that has proved useful as an experimental tool to investigated memory impairment in patients with neurosurgical lesions effecting memory. The advantages of this approach from an experimental point of view have been discussed, and the clear finding of the experiment validates the use of this technology in this context.

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Virtual reality applications for the assessment and rehabilitation of attention and visuospatial cognitive processes: an update

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ABSTRACT

Virtual Reality (VR) technology offers potential for sophisticated new tools that could be applied in the areas of neuropsychological assessment and cognitive rehabilitation. If empirical studies demonstrate effectiveness, virtual environments (VEs) could be of considerable benefit to persons with cognitive and functional impairments due to traumatic brain injury, neurological disorders, and learning disabilities. Testing and training scenarios that would be difficult, if not impossible, to deliver using conventional neuropsychological methods are now being developed to take advantage of the attributes of VEs. VR technology allows for the precise presentation and control of dynamic multi-sensory 3D stimulus environments, as well as the recording of all behavioral responses. This paper will focus on the progress of a VR research program at the University of Southern California that has developed and investigated the use of a series of VEs designed to target: 1. Molecular visuospatial skills using a 3D projection-based ImmersaDesk system. and 2. Attention (and soon memory and executive functioning) processes within ecologically valid functional scenarios using a Virtual Research V8 Head Mounted Display (HMD). Results from completed research, rationales and methodology of works in progress, and our plan for future work will be discussed. Our primary vision has been to develop VR systems that target cognitive processes and functional skills that are of relevance to a wide range of patient populations with CNS dysfunction. We have also sought to select cognitive/functional targets that intuitively appear well matched to the specific assets available with the VR equipment that is available for our use.

1. INTRODUCTION

We are experiencing the emergence of an information society, increasingly based on the production and exchange of information. As this vision unfolds, those who are able to thoughtfully develop and apply evolving computer and information technology (CIT), will be in a position to impact fundamental changes for advancing human welfare. In order to maximize the potential benefits of this paradigm shift for those with special needs it is necessary to focus efforts on the development and application of more usable and accessible CIT. This direction fits well with the "Information Society for All" concepts that have recently been addressed in the human-computer interaction literature (Stephanidis & Salvendi, et al, 1999). Efforts in this area support the development of CIT that accommodates the broadest range of human abilities, skills, requirements and preferences. The potential results of such efforts could substantially redefine the assessment and rehabilitative strategies that are used with clinical populations. One form of CIT that has shown considerable promise for clinical application is Virtual Reality.

Virtual Reality (VR) is rapidly evolving into a pragmatically usable technology. With continuing advances in the areas of computing power, graphics and image capture, display technology, interfacing tools, immersive audio, haptics, wireless tracking, voice recognition, intelligent agents, and VR authoring software, more powerful, naturalistic and usable Virtual Environments (VEs) will become possible. Concurrent with these technological developments, scientists and clinicians have recognized VR's potential as a useful tool for the study, assessment, and rehabilitation of cognitive processes and functional abilities (Brown et al, 1997; Pugnetti et al, 1995; Rizzo & Buckwalter, 1997; Rose, 1996). Much like an aircraft simulator serves to test and train piloting ability, VEs can be developed to present simulations that target human cognition and behavior in normal and impaired populations. Individuals who may benefit from these applications include persons with cognitive and functional impairments due to traumatic brain injury (TBI), neurological disorders, and developmental/learning disabilities. The capacity of VR technology to create dynamic, multi-sensory, three-dimensional (3D) stimulus environments, within which all behavioral responding can be recorded, offers clinical assessment and rehabilitation options that are not available using traditional neuropsychological methods. In this regard, a growing number of laboratories are developing research programs investigating the use of VEs for these purposes and initial exploratory studies reporting encouraging results have begun to emerge (Rizzo et al, in press). This work has the potential to advance the scientific study of normal cognitive and behavioral processes, and to improve our capacity to understand, measure, and treat the impairments typically found in clinical populations with central nervous system (CNS) dysfunction.

VR applications are now being developed and tested which focus on component cognitive processes including: attention, executive functions, memory, and spatial abilities. Functional VE training scenarios have also been designed to test and teach instrumental activities of daily living such as street-crossing, automobile driving, meal preparation, supermarket shopping, use of public transportation, and wheelchair navigation. More involved discussion of the rationales, issues and application of VR for neuropsychological targets can be found in a number of previous papers (Rizzo & Buckwalter, 1997; Rizzo et al, in press). These initiatives have formed a foundation of work that provides support for the feasibility and potential value of further development of neuropsychological VE applications. The success of these VE scenarios give hope that the 21st century will be ushered in with new and exciting tools to advance a field that has long been mired in the methods of the past. Additionally, the emergence of PC-powered VEs that are less expensive, yet still well rendered and responsive, will result in more readily available systems and support more widespread VR application. Improved access to VR technology would promote both clinical goals and the independent replication of research findings needed for scientific progress in this field. As well, major funding agencies in the USA have realised the potential value of effort in these areas. For example, on a more global level the National Science Foundation stated in a recent VR program announcement that, "…Computer simulation has now joined theory and experimentation as a third path to scientific knowledge. Simulation plays an increasingly critical role in all areas of science and engineering . . . " (p.1) (NSF PA# 98-168). More specific to the application of VR in neuropsychology, the National Institute on Disability and Rehabilitation Research (NIDRR) in a recent position statement highlighted that, "…The benefits of combining virtual reality with rehabilitation interventions are potentially extensive…" and specifically calls for research "….to determine the efficacy of virtual reality techniques in both rehabilitation medicine and in applications that directly affect the lives of persons with disabilities" (NIDRR webpage, August 24, 1999).

In view of the above issues, this article will focus on the progress of a VR research program at the University of Southern California that has developed and investigated the use of a series of VEs designed to target the assessment and rehabilitation of cognitive and functional processes. Results from completed research, rationales and methodology of works in progress, and our plan for future work will be discussed. Our primary vision has been to develop VR systems that target cognitive processes and functional skills that are of relevance to a wide range of patient populations with CNS dysfunction. We have also sought to select cognitive/functional targets that intuitively appear well matched to the specific assets available with the VR equipment that is available for our use. Consequently, we have evolved two parallel programs: 1. The targeting of molecular visuospatial skills using a 3D projection-based ImmersaDesk system. and 2. The targeting of attention (and soon memory and executive functioning) processes within ecologically valid functional scenarios using a Virtual Research V8 Head Mounted Display (HMD). At the time of the initial development of these applications, we used SGI Onyx systems to render and interact with the scenarios. However, we have begun the process of transferring the scenarios to a PC platform in view of the rapid advances that have occurred in this area lately and due to the desire to develop more economical systems that could reach a wider range of potential users.

2. VISUOSPATIAL APPLICATIONS

We have developed a component-based approach for addressing visuospatial ability through the use of a suite of ImmersaDesk-delivered (see Figure 1) three dimensional (3D) applications targeting mental rotation (MR), depth perception, field dependence (3D rod and frame test), static and dynamic manual tracking, and visual field specific reaction time. These scenarios were designed to leverage the 3D interactive assets available with this type of projection-based system in the development of a series of tasks that could assess and possibly rehabilitate these more molecular components of visuospatial functioning. Generally, spatial ability is an important domain to consider in the assessment of neurological disorders, traumatic brain injury, and neuropathological conditions of aging. For example, spatial orientation abilities are an important variable in the differential diagnosis of dementia. Research indicates that victims of Alzheimer's disease have an 84% incidence of spatial orientation impairments compared to only a 4% incidence in frontotemporal dementia (Miller et al, 1997). Impairments in spatial orientation were also shown to be more common in Alzheimer's disease compared to both normal elderly and those with vascular dementia (Gianotti et al, 1992; Signorino et al, 1996). Similar impairments have been observed following the occurrence of traumatic brain injury and stroke (Lezak, 1995). Tests of spatial ability, including the MR variable, are also commonly used for the study of brain/behavior relationships, particularly regarding sex differences in cognition. Mental rotation ability produces the most consistent and sizeable sex differences, in favor of males, in the cognitive literature (Voyer et al, 1995). Consequently, a lively literature has emerged examining MR, as well as with other cognitive variables where female advantages appear (i.e., verbal fluency and fine motor skills among others). Studies have reported differential cognitive performance due to such hormonal factors as onset of menopause, estrogen and testosterone administration, and stage of the menstrual cycle (Gouchie and Kimura, 1991; Kampen and Sherwin, 1994; Silverman and Phillips, 1993). However, these findings remain controversial. Several studies have attempted to explain cognitive sex differences as the product of sociocultural influences, and on non-specific testing performance factors related to the use of timed tests and "reluctance to guess" factors (Richardson, 1994; Qubeck, 1997; Delgado and Prieto, 1996). Also, it has also been suggested that the effect size in gender differences has been decreasing in recent years. However, meta-analytic research has argued against these conclusions (Masters and Sanders, 1993; Voyer et al, 1995). These issues, (which are ongoing research interests at our lab within the USC Alzheimer's Disease Research Center), and our interest in the potential usefulness of VR, motivated our development of the Virtual Reality Mental Rotation/Spatial Skills Project.

2.1 Brief Review of Initial Mental Rotation Study with Young Adults

Our initial study focused on the development of a VE for the study, assessment, and rehabilitation of a visuospatial ability referred to as Mental Rotation (MR). MR was targeted via a manual spatial rotation task that required subjects to manipulate block configurations within a VE. MR is a well-studied visuospatial variable, which can be described as a dynamic imagery process that involves "turning something over in one's mind" (Shepard and Metzler , 1971). Everyday life situations rely on this ability to use imagery to turn over or manipulate objects mentally. These include automobile driving judgements, organizing items in limited storage space, using a map, sports activities, and many other situations where one needs to visualize the movement and ultimate location of physical objects in 3D space. High-level mathematics performance has also been linked, in large part, to MR ability (Casey et al, 1995). Indeed, in a recent Los Angeles Times interview, it was noted that world renown physicist, Stephen Hawking, "…translates mathematics into geometry, and turns around geometrical shapes in his head." (Cole, 1998). The initial MR investigations began almost 30 years ago with the work of Shepard and Metzler (1971) who tachistoscopically presented pairs of two-dimensional perspective drawings to subjects and required them to make judgements as to whether the 3-D objects they portrayed, were the same or different (see Figure 2). A near perfect linear relationship was found between the amount of angle rotation difference between the pairs of objects, and the reaction time to decide whether or not the objects were the same or different. Since precise mathematical relationships between hypothesized mental representations and behavioral performance are relatively rare, MR has been the focus of much research. Traditional 2D measures for the assessment of mental rotation have produced intriguing findings, yet lack the precision needed to better understand this spatial ability. The most common test uses two-dimensional image stimuli that portray three-dimensional objects and requires mental processing of the stimuli without any motoric involvement (Vandenberg and Kuse, 1978). The use of VR for the assessment of visuospatial abilities supports greater control and description of 3D stimuli along with more precise measurement of responses. This should allow more accurate characterization of cognitive processes involved in visuospatial skills than afforded by standard measures. In addition, by examining changes in spatial performance following VE exposure, useful rehabilitation options may emerge.

In our initial VE feasibility study targeting MR we tested 18-40 year old males and females. Subjects were presented with a specific configuration of 3D blocks within a virtual environment (similar to Figure 2). The stimuli appear as "hologram-like" 3D objects floating above the projection screen and the participant manipulates the control object by grasping and moving a sphere shaped "cyberprop" which contains an Ascension "Flock of Birds" tracking device. The speed (time to complete) and efficiency (ratio of ideal to actual rotations) of their movements to superimpose a replica design upon the target was measured and recorded over 140 trials (20 pre/post test trials and 100 intervening training trials). All manner of angular disparity and rotational axis combinations were programmed into the system allowing for the hierarchical presentation of cognitive challenges. Upon successful superimposition of the control and target objects, a "correct" feedback tone was presented and the next trial began. A control group was also tested that were administered all facets of the experiment, except that they performed crossword puzzles in place of the VR interaction. Details on the relevance of this application and the specific methodological details of this work can be found in Rizzo et al, (1998). A number of encouraging findings emerged including minimal side effect occurrence, reasonable psychometric properties of the VE test, provocative relationships with standard NA tests, a lack of gender differences compared to the pencil and paper performance, training improvement and significant transfer of training with low initial MRT pencil and paper performers.

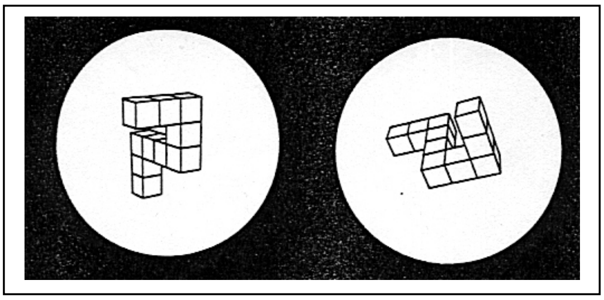

Figure 1. *ImmersaDesk 3D projection Display System.* **Figure 2.** *Mental rotation stimuli.*

2.1.1 Side Effects. A split plot factorial ANOVA indicated that the interaction between group (VR and control) and occasion (pre and post testing) was significant for the amount of side effects reported. While the trend was for the VRSR group to report increased side effects, the trend for the control group to report fewer side effects also contributed to this interaction. Post hoc analyses of the VR group found that the only item where there was a significant increase at post testing was blurred vision.

2.1.2 Reliability. The VR-delivered MRT's reliability was in the moderate range on calculations of internal consistency and matched parcel reliability. Typically, neuropsychology instruments boast reliability coefficients ranging from 0.80 to 0.95 (Mitrushina et al, 1999). Sattler (1988) asserts that a neuropsychology test's reliability coefficient must approximate or exceed 0.80 in magnitude, while coefficients of 0.90 or above are considered the most desirable. The VR MRT's reliability fell below this range with a Coefficient γ equal to 0.71 on its Speed Index and 0.73 for the Efficiency Index. Cronbach's alpha for these indices were 0.65 and 0.69 respectively. However, our reliability findings do not negate the utility of this tool as a useful neuropsychological instrument. Nunnally and Bernstein (1993) contend that in the early stages of construct validation, it is still useful to investigate measures evidencing only modest reliability (i.e. .70). Furthermore, only after investigating whether corrections for attenuations will increase reliability is it useful to increase the number of items and reduce the measurement error in hopes of enhancing an instrument's reliability. As a point of comparison, the test-retest reliability was .60 for the paper and pencil MRT. Thus, we interpret our findings to indicate that the VR MRT has potential as a reliable measure and will require further study.

2.1.3 Concurrent Validity. Pearson Product-Moment correlations between the VR time to complete (Speed Index) and all standard measures of neuropsychological functioning yielded a number of statistically significant effects. It was highly correlated with the Efficiency Index ($r = .76$, $p < .001$) and with the paper and pencil Mental Rotation Test (MRT) ($r = .45$, $p = .01$). It also correlated significantly with tests of visual memory under both immediate ($r = .50$, $p = .006$) and delayed ($r = .48$, $= .008$) conditions. There was a significant association with visual attention as measured by Trails A ($r = .38$, $p = .04$). There were also strong correlations with two measures of executive functioning one that includes a strong visuoconstructional component (Trails B; r = .46, p = .01, WAIS Block Design; r = .64, p < .001). Surprisingly, the Speed Index on VR MR testing also was associated with aspects of verbal learning notably the consistency of items recalled over the 5 trials of the California Verbal Learning Test (CVLT) (r = .52, p = .005) and the number of perseverations, or times when subjects repeated the same word. These findings may relate more to the ability to maintain concentration when presented with a large amount of new information (working memory) than to verbal memory per se. (Note that the direction of all correlations is such that slower completion time is associated with worse performance on each test) Correlations between the Efficiency Index and other neuropsychological tests were minimal. As reported above, Efficiency Index did correlate significantly with the Speed Index on the VR MRT. It also correlated significantly with one executive functioning test (WAIS Block Design) which requires manipulation of physical blocks.

A comparison of associations between the paper and pencil MRT with the other neuropsychological tests provides a useful reference point for interpreting the above correlations. The tests that correlated with the MRT are generally very consistent with the tests that correlated with the VR Speed Index with one notable exception. While performance on the Judgement of Line Orientation (JLO) was not associated with the VR MR testing, it was strongly correlated with the MRT. The JLO is a two-dimensional task that evaluates the ability to perceive spatial orientation. That it would be associated with the ability to mentally rotate two dimensional portrayals of 3D objects and not with the ability to physically manipulate 3D virtual objects suggests that one of the major cognitive components underlying ability on the MRT may relate to the person's ability to construct and manipulate 3D images from two-dimensional perception and future investigations in this area are planned.

2.1.4 Sex Differences on Rotational Tasks. Men scored significantly better on the MRT given before the VR testing/training (p < .04). By contrast, there were no differences between men and women on either the Speed Index or the Efficiency Index of the VR testing (p's > .8). Interestingly, the difference between men and women on the MRT after completing the VR training was no longer significant. The existence of gender differences on the MRT is well established but the mechanism for this difference is not identified. That women can manipulate and successful rotate 3D objects as efficiently as men while they cannot visualize the same process as well with 2D stimuli has potentially useful implications for understanding sex differences in brain functioning that influence cognition.

2.1.5 VR and Training/Transfer Issues. Subjects showed significant improvement on the VR testing after completing 100 training trials for both the Speed Index (p < .001) and Efficiency (p = .03). Subjects in the VR group showed a non-significant trend toward improved performance on the MRT (p < .06). When the changes in MRT performance between the VR and control group were compared by utilizing a split plot factorial ANOVA, the interaction between group and change over the two testing occasions was non-significant. This indicates that VR exposure did not have a specific effect on improving performance among *all* subjects. However, upon further inspection, this result may be in part due to a low ceiling for MRT performance with the subjects in this sample. Our sample of subjects was notable for performing much better on the MRT than is reported in studies with broader populations. If rotational skills can be trained, it would seem likely that individuals with high existing levels of rotational ability would be less likely to show improvement than individuals with less ability. In this regard, we examined how individuals who had relatively poor initial MRT scores perform after VR exposure. To directly test this, we divided subjects into groups, based on the MRT scores at the pre-testing. We used a cutpoint of 20 (out of a possible 40) to create a group of subjects with scores closer to those reported in other studies. Again using a split-plot factorial design, we found a significant (p <.02) interaction between group (VR and control), MRT group (≤ 20, > 20) and occasion (pre and post MRT) such that low scorers on the MRT who were in the VR group improved significantly more than other groups (see Figure 3).

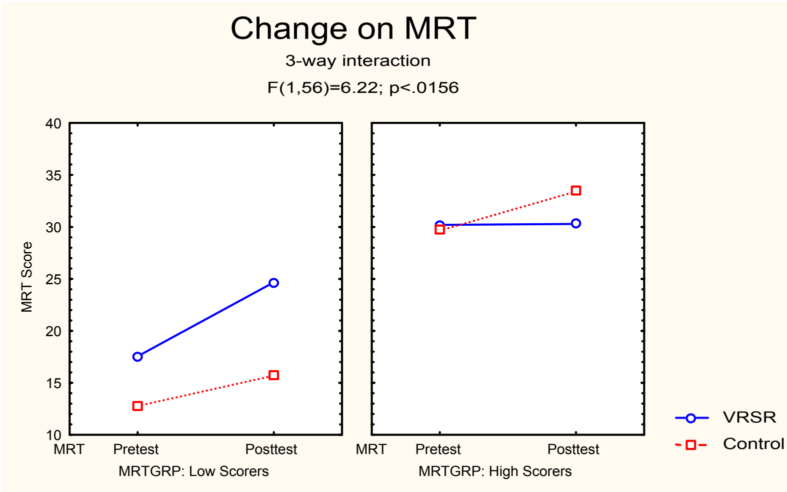

Figure 3. *Pre/Post Performance Changes on MRT with low/high initial performers for VR vs. Control groups.*

This leads to the intriguing suggestion that rotational skills can be trained in VR when they are relatively poor to begin with. This could have implications for cognitive rehabilitation strategies aimed at impaired populations. This experiment indicated that immersive VE-delivered physical rotation training with the MR stimuli may help improve imaginal mental rotation abilities. This assertion is bolstered by a recent study which concluded that rotary object manipulation and mental object rotation share a mutual process that is believed to direct the dynamics of both imagined and actual physical object reorientation (Wohlschlager and Wohlschlager 1998). By conducting additional studies on this VE system with the elderly, and persons with TBI or neurological disorders, the feasibility and effectiveness of this novel technology for assessment and rehabilitation purposes will be better understood.

2.1.6 Quasi-experimental Follow-up Study. Following this study, we conducted a quasi-experimental design investigation to collect pilot data on what factors may have mediated the performance improvement seen on the pencil and paper MRT following VR training in low initial performers. We videotaped one of the investigators performing well-trained executions of the 140 VR MR trials. The tape was shot in mono-mode (2D) and the resulting video presented crisp moving images of the blocks being successfully superimposed in a very efficient manner. Twenty-four college students (aged 18-36) were administered the MRT and then asked to watch the video tape, followed by administration of the same alternate form MRT as used in the previous study. In this manner, subjects *passively* observed the 2D representations being dynamically superimposed to determine if observation effects might produce equal performance increases as seen with the 3D active interaction study. These subjects had initial MRT scores that were similar those in our "MRT Under-20" sample and following simple video observation of 2D superimposition of block configurations, subject's performance mirrored the control group in the previous study with minimal and non-significant gains (2.3 points compared with an 8-point gain seen with the active VR group in the previous study). While these data are based on a less controlled quasi-experimental design approach, they are suggestive that MR training improvements in low initial performers may require the type of active interaction with 3D stimuli that is characteristic of VR training. A more controlled version of this study separately examining active vs. passive and 2D vs. 3D components is currently in the planning stage.

2.2 *Expanded VR Visuospatial System Experiment with Elderly Subjects*

Following the completion of the above study, we expanded our VR visuospatial system by developing a series of 3D scenarios to investigate depth perception, field dependence (3D rod and frame test), static/dynamic manual tracking, and visual field specific reaction time using the ImmersaDesk system. A battery of standard neuropsychological tests were administered to 30 healthy elderly male and female subjects (age 65-86) along with testing on the following VR scenarios (in addition to the spatial rotation task outlined above):

2.2.1 Visual Field-Specific Reaction Time Task. This series of tasks tested visual-field specific reaction time performance to stimuli that were presented in a consistent Left of Right location (regardless of shifts in the subjects' head position) via input from the tracking system contained in the *Crystal Eyes* stereoglasses. Participants were asked to focus their gaze on an "X" presented at the center of the screen and instructed to anticipate a dot to flash either to the left or right of the "X" and to press the response button (using the

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standard ImmersaDesk response wand) with their thumb as soon as they see the dot. They were told that they will respond best by fixating on the center "X" since they were not be able to anticipant when or from which side the stimulus will appear. Twenty blocks of ten trials were administered (200 trials) with participants instructed to switch between their left and right hands for alternate blocks of trials. A "water drop" sound was utilized to alert participants to the beginning of a series of 10 trials. The stimuli appear at six degrees to the left or right of the midpoint at a width of 0.5 degrees. Random intervals are timed from 0.5 to 2.0 seconds, and intervals were counterbalanced. The flash duration was at least 0.05 seconds, and if a person missed the flash, the timeout period was 2 seconds after the flash occurs. This task provided a baseline of reaction time performance, and data on brain laterality factors that may underlie processing speed for these types of vigilance tasks.

2.2.2 Depth Perception Tasks. The next series of visuospatial tasks consisted of three depth perception scenarios. The first scenario required subjects to match two cubes (*identical object* depth alignment). Participants were instructed to familiarize themselves to the task by moving the standard ImmersaDesk response wand forwards and backwards in relation to the screen and to notice that this action moved one of the cubes towards or away from them. A static target cube was positioned at varying distances from the subject. The following instructions were given: "The task is to move the cube that you are controlling until it matches the position of the static target cube. When you are satisfied that the cubes are the same distance from you, click the response button of the wand. Respond as accurately as you can. At the tone, the task will begin and when you respond, a chime will sound and you will continue with the next trial of the matching task with the static target cube moving to a new position. Are you ready?" The second depth perception task involved a static cube and a larger-sized movable ball (*dissimilar object* depth alignment) that subjects were able to interact with similar to the previous task. The final depth perception task involved two vertical lines (*vertical line* depth alignment). The participants were instructed to move the line on the right side of the screen by moving the wand back and forth. When the participant judged the two lines to be at the same distance (matched), he/she pushed the response button. After each response, a chime sounded and a new line appeared. Five trials of each depth perception task were administered.

2.2.3 3D Field Dependency Task. To assess field dependency, a "3D virtual rod and frame test" was developed. A yellow frame seemingly afloat in space appeared on the screen along with a centered white rod, the orientation of which was controlled by the participant's wand movements. On each trial, the yellow frame was positioned slightly different from the one previous and the white bar appeared at a different orientation. Each participant was instructed to respond by pressing the button on the wand when they have positioned the white bar vertically or perpendicular to the floor regardless of the position of the frame. Five trials of this task were presented.

2.2.4 Manual 3D Tracking Task (Static & Dynamic). During the *static* 3D manual tracking task, two balls (a blue one on the left and a red one on the right) appeared on the projection screen with a white line running horizontally between them. Participants were instructed to position the "wand-controlled" cross hairs in the center of the blue ball on the left. They were then instructed to move the ball along the white line using the cross hairs to "push" it, and were told that in order to make the ball move, the cross hairs must be in the center of the ball, intersecting the cross hairs closest to the white line. The task involves moving the blue ball to the end of the line where the red ball was, and then back to the original position. The *dynamic* 3D manual tracking task required the subject to keep a moving figure ("Tinkerbell") inside a blue 3D bubble (or orb) that was controlled with the wand. During the first task group, the figure's movement was relatively fluid and stereotypic, consisting of one trial each of x, y, and z rotations (circular paths). The second task group consisted of 4 paths of different speeds and lengths. During this portion of the task, the figure's actions increased in speed, became increasingly erratic, and the level of difficulty increased for successful tracking. The entire dynamic 3D manual tracking task took approximately 85 seconds to complete.

The primary purpose of this work was to determine how well elderly individuals could perform these visuospatial tasks in VR, and then apply this healthy group's performance data as a reference sample for future comparisons with elderly persons with various forms of dementia, as well as with a younger sample (that is currently being tested) to determine age-related changes in visuospatial performance. We were also concerned with measuring the occurrence of VR side effects with this age-group and administered pre/post Simulator Sickness Questionnaires (Kennedy et al, 1993) to determine the feasibility of future VR applications with older adults. Gender differences in visuospatial performances and comparisons of results with standard visuospatial testing instruments are also of significant interest in this research. Aside from our motives to devise better visuospatial tools for diagnostic purposes, we are focusing on the added value of testing/training these cognitive processes using the dynamic 3D interactive assets that are available with VR compared to the static 2D tools that currently make up the bulk of traditional approaches in this area.

Thus far, preliminary analyses of this data have indicated a low occurrence of self-reported negative VR side effects. Additionally, sex differences (in favor of males) were found on standard visuospatial psychometric assessment tools. These include, pre-VR testing MRT (t(28) = 3.33, p = .002), post-VR MRT (t(28) = 2.75, p = .010), Judgement of Line Orientation (t(28) = 5.05, p = .000), WAIS-R Block Design (t(28) = 3.01, p = .006), Matrix Reasoning (t(28) = 2.04, p = .051) and WAIS-R Arithmetic (t(28) = 7.70, p = .001). Comparisons between the standard neuropsychological test results and VR performance testing is currently being analyzed and will be presented at the conference. At the time of this writing we have analyzed the "identical object" VR depth perception task and no male/female difference were found. One of our primary interests involves examining VR visuospatial performance to determine if females' performance *doesn't* differ from males, as found in our younger sample. This finding would be of value for later use of these VR tools for detecting visuospatial declines in women due to early-onset dementing conditions that may be masked on standard tests due to the generally lowered test performance seen in women.

We plan to follow up our current work with studies involving populations with CNS dysfunction (Alzheimer's, Stroke, TBI, etc.) and then develop a 3D desktop system using *Crystal Eyes* shutter glasses to run comparative tests to determine if these scenarios can be successfully delivered on a less expensive and more accessible platform. Our longer-term plan is to produce a suite of standardized VE-delivered 3D visuospatial assessment and rehabilitation tools and are currently designing new tasks to target 3D line bisection, figure/ground judgements and other perceptual reasoning targets for use by researchers and clinicians. Videotapes of the scenarios described above will be shown during the ICDVRAT 2000 conference presentation along with more evolved data analyses that are still in progress at the time of this writing. More detailed information on the rationale, equipment, and methodology for this work can be found in McGee et al, (2000).

Figure 4. *Scenes from the "Virtual Classroom" for Assessment of Attention Deficit Hyperactivity Disorder.*

3. ATTENTION PROCESS APPLICATIONS USING HMD'S

A second line of research that is being addressed in our lab concerns the development of a series of ecologically valid functional VEs that will serve as platforms for addressing a range of cognitive and functional processes. Our first effort in this direction is in the development of a HMD-delivered classroom scenario for the assessment and rehabilitation of attention processes (see figure 4). While this platform is ultimately envisioned to be capable of delivering cognitive testing and training protocols that could address other cognitive processes including memory and executive functions, we are initially targeting attention. Attention processes are the gateway to information acquisition and serve as a necessary foundation for most higher learning. Impairments in attention can be found in clinical populations across the lifespan and are commonly seen in persons with Attention Deficit Hyperactivity Disorder (ADHD), TBI, and as a feature of various forms of age-related Dementia (e.g., Alzheimer's Disease). Little VE work has been done with this "basic" gateway cognitive process thus far, which is surprising in view of the relative significance of attention impairments seen in a variety of clinical conditions. More effective assessment and rehabilitation tools are needed to address attention processes for a variety of reasons. In children, attention skills are the necessary foundation for future educational activities. Specific to ADHD, improved assessment of attention is vital for diagnostic purposes, special education placement decisions, determination of the use and effectiveness of pharmacological treatments, and for outcome measurement following interventions. Regarding TBI, even with mild trauma, these patients often suffer attention deficits that require focus as a precursor to rehabilitative work on higher cognitive processes (i.e., memory, executive functions, and problem solving). Also, even if higher processes are unable to be remediated in cases of severe TBI, some level of attention ability is essential for vocational endeavors, functional independence, and quality of life pursuits. With the elderly, a more fine-grained assessment of basic attention deficits may provide an early indicator of dementia-related symptoms, could suggest functional areas where an older person might be at risk (i.e., automobile driving, operating machinery, etc.), and guide development of compensatory strategies useful to maximize or maintain functional independence. HMDs are well suited for these types of applications as they present a controlled stimulus environment where cognitive/attention challenges can be administered along with the precise control of "distracting" auditory and visual stimuli. This level of experimental control may also allow for the development of attention assessment and rehabilitation tasks more similar to what is found in the real world.

Our first effort in this area has involved the development of a virtual "classroom" specifically aimed at the assessment of ADHD. VE technology appears to provide specific assets for addressing impairments seen in ADHD that are not available using existing methods. The scenario consists of a standard rectangular classroom environment containing desks, a male or female teacher, a blackboard across the front wall, a side wall with a large window looking out onto a playground and street with vehicles and people, and on each end of the opposite wall, a pair of doorways through which activity occurs. Within this scenario, children's attention performance is assessed while a series of typical classroom distracters (i.e., immersive audio supported ambient classroom noise, movement of other pupils, activity occurring outside the window, etc.) are systematically controlled and manipulated within the virtual environment. The child sits at a real desk while seeing a virtual desk in the HMD within the virtual classroom. On-task attention can be measured in terms of performance (reaction time) on a variety of attention challenges that can be adjusted based on the child's expected age/grade level of performance. For example, on the simpler end of the continuum, the child can be required to press a response button upon the direct instruction of the virtual teacher or whenever the child hears the name of a specific target color mentioned by the teacher (*focused* or *selective* attention task). *Sustained* attention can be assessed by manipulating the time demands of the testing. More complex demands requiring *alternating* or *divided* attention can be developed whereby the student needs to respond only when the teacher states the target color in relation to an animal (i.e., the brown *dog,* as opposed to the statement, " I like the color *brown*") and only when the word "dog" is written, or a picture of a dog appears on the blackboard. In addition to attention-driven reaction time performance, behavioral measures that are correlated with distractibility and/or hyperactivity components (i.e., head turning, gross motor movement), and impulsive non-task behaviors (time playing with "distracter" items on the desk) can be measured via strategically located trackers. Our first study is presently comparing ADHD diagnosed children (aged 8-12) with a non-diagnosed control group using more basic attention challenges that are commonly seen on currently available continuous performance tasks and in common classroom tasks (listen-look-respond).

Figure 5. *The Virtual Office Scenario.*

This work is currently in progress and is in the user-centered design phase. In this phase we are testing children on basic selective and alternating attention tasks, soliciting their feedback pertaining to aesthetics and usability of the VE, and incorporating some of their comments into the actual iterative design-evaluate-redesign cycle. Thus far we have tested 10 non-diagnosed children (ages 6-12) and initial results indicate little difficulty in adapting to use of the HMD, no self-reported occurrence of side effects determined by post-interviews using the Simulator Sickness Questionnaire (Kennedy et al, 1993) and excellent performance on the stimulus tracking challenges. Our initial clinical trial is schedule to commence in August 2000. More detailed information on the rationale, equipment, and methodology for this project can be found in Rizzo et al, (2000).

Other scenarios (i.e., work situations, home environments, etc.,) using the same logic and approach are being conceptualized and developed to address cognitive/functional processes that are relevant for a range of other clinical populations. For example, we have now constructed a virtual "Office" environment that evolved from expanding some of the basic design elements of the Classroom VE (see Figure 5). As with the Classroom VE, the user will sit at a real desk, but within the HMD, they will see the scenes that make up the virtual "office". The virtual desk contains a phone, computer screen, and message pad, while throughout the office, a virtual clock ticks in real-time, and a variety of human avatar representations of co-workers/supervisors can be actively engaged. Various performance challenges can be delivered via the computer screen (visual mode), the phone (auditory mode), and from the avatar "supervisors" verbal directions. These commands can direct the user to perform certain functions within the environment that can be designed to assess and rehabilitate attention, memory, and executive functions. For example, to produce "prospective" memory challenges, the user might receive a command from the virtual supervisor to "turn-on" the computer at a specific time to retrieve a message that will direct a response. This will require the user to hold this information in mind, monitor the time via the wall clock and then initiate a response at the appropriate time. By adding multiple contingent commands, both attention and executive functioning can be addressed. As well, the influence of distraction can be tested or trained for via the presentation of ambient office sounds (i.e., radio announcements, conversations, etc.), activity occurring outside the window (cars rumbling by), or by producing extraneous stimuli on the desktop (i.e., irrelevant, yet "attention-grabbing" email messages appearing on computer screen). Essentially, functional work performance challenges typical of what occurs in the real world can be systematically presented in an ecologically valid VE. The variety of scenario complexity and potential usefulness of such a tool is only limited by the developer's imagination and a thoughtful informed assessment of the needs of the user! Such virtual environments underscore the challenges and opportunities that VR offers for the advancement of neuropsychological assessment and cognitive rehabilitation!

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Session VIII. Interfacing to Virtual Environments II

Chair: Patrick Langdon

Interactive interfaces for movement rehabilitation in virtual environments

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ABSTRACT

This paper discusses a system for movement rehabilitation that uses low-cost widely available input devices supporting force-feedback, enabling the design of an individualised therapy curriculum. Interactive 3D environments present tasks that can be adapted in terms of complexity and ease of goal attainment. The system is focused upon promoting increase in the range of movement, control of tremor, control of limb velocity and control of smoothness of movement. Our system exploits the use of augmented feedback to enable the patient to identify the strategies and sensory cues that support re-organisation of the impaired motor response. Stress is laid on flexible mapping between the limb movement and the virtual environment action; this provides an extensible system to cope with diverse movement (dis)abilities and also encompass advances in input device technology.

1. INTRODUCTION

The incidence of stroke is steadily increasing in the population of Europe and the USA. There is a high incidence of both cognitive problems and movement problems following stroke. The typical pattern of impairment in the motor system is loss of muscular control and impairment of muscular sensation on the side contra-lateral to the site of damage (hemiparesis). The degree of hemiparesis and its topology will vary between individuals, but some general patterns of dysfunction may be evident. Limb control which is normally ascribed to the cortico-spinal, pyramidal tract (e.g. fingers, lower limb) is often impaired, whereas more proximal areas may be less profoundly affected. It is therefore common for patients to exhibit problems with manipulative movements, on the contra-lateral side, following unilateral stroke. The lower limbs may also be affected and because effective balance and locomotion requires co-ordination of both lower limbs, there may be a general disruption to gait and standing balance.

There may be some degree of recovery of function during the first 6 months, which does not seem to be dictated by the type of therapeutic intervention. This generally follows a negatively accelerating curve, such that rapid and ‘promising’ improvement may be seen in the first 3 months, but if no intervention is introduced this will plateau at a level well below what is optimal. The role of therapy, therefore, is to enhance the degree of recovery and to try and avoid an early plateau in the degree of functional recovery. Whether this goal can be met by many conventional therapies is a matter of debate (Pomeroy and Tallis, 2000), but there are reasons why this is not a simple question to address. Firstly, it is not clear how goal achievement should be measured and whether the return of ‘normal function’ precludes atypical patterns of movement (Latash and Anson, 1996). Secondly, the efficacy of a specific therapy does not rest solely in the procedures and principles of the method, but on the cognitive, emotional and social factors that accompany the patient (Maclean and Pound, 2000). Motor learning following cortical injury is a considerable challenge that requires a steady re-learning of what had previously been everyday skills. The majority of grounded therapeutic procedures require the repetition of simple actions and improvement may be slow. Coupled with this a rehabilitation ward may not provide a particularly engaging environment. Walter and Kamm (1996) have suggested that it may even be negatively disposed to learning: ‘individuals with movement disorders begin resolving the priorities of their pathologic sensorimotor system while the niche that they occupy (e.g., acute care hospitalisation) is perceptually, motorically, and functionally impoverished’. Even outside of the ward, the tasks presented to outpatients may not provide them with a stimulating and fulfilling set of activities. A study by Newall et al (1997) recorded that the amount of time spent by a patient on ‘homework’ and active recreation accounted for only 1.7%-5.4% of a 24-hour period.

Computer assisted or 'virtual environment' systems have a potential role in enhancing the rehabilitation environment and the procedures or tasks that are presented to a patient. We describe a system that provides a user with the facility to practice skilled movement in virtual environments:

The system is adaptable to user abilities to provide access even when residual movement abilities may be poor. The user can benefit from practising tasks, and achieving goals, with their residual motor control that would otherwise be impossible.

Secondly the system has the potential to be used in domiciliary rehabilitation and therefore make the transition from hospital-based to domiciliary rehabilitation more seamless. Whereas the use of rich, task driven, computer-generated environments may help to offset the tendency for outpatients to neglect their 'homework'.

A third benefit is that tasks for such a system are designed once and used many times, with the implication that if a task designed at one centre seems particularly effective it could readily be distributed to other rehabilitation units. This could lead to a more standardised, or repeatable, therapy curriculum with best practice becoming embedded in the task design over time.

The system is not seen as a substitute for hands-on therapeutic input, but a supplement, where a therapist/clinician can set an individual task, which the patient can practice, without direct supervision. Clinicians are not required to guide the user through the task, or provide feedback – though additional input might be given – freeing them to focus on patient progress and strategies on further intervention. Additionally, the system can provide data on progress for individuals that may be collated across the recovery period or across individuals to provide a database on patient progress.

Despite the promise of virtual interfaces for rehabilitation there are a considerable number of questions that arise regarding what a system should encompass, what should be excluded and how the system might be tuned, or adapt, to individual patient requirements, without becoming so diffuse that it requires on-site programming support.

2. RESEARCH IN MOTOR LEARNING

2.1 What aspects of motor control?

There is a wide range of disorders that have a major effect on motor system functioning, such as Stroke, Cerebral Palsy, Parkinson's Disease and Multiple Sclerosis. There are generic manifestations of such pathologies, however, that arise from the neurophysiology of the motor system. The dysfunction resulting from *Cardio-Vascular Stroke*: has already been outlined and is typically a loss of muscular control and the impairment of muscular sensation on the side opposite to the site of damage, particularly with respect to hand and finger control or control of the contra-lesional foot. Muscular weakness in stroke may in some case progress into spasticity.

Congenital Cerebral Palsy occurs in approximately 0.1% of live births, although the incidence may rise to 4% amongst very low birthweight infants. The children first exhibit hypnoticity (a lack of muscular tone), but this eventually becomes a pattern of either spasticity (hypertonicity) or athetosis (involuntary limb motion) or both. The problem is fundamentally different from that of the stroke patient, but the resulting difficulty in tackling everyday tasks share similarities

Parkinson's Disease arises due to a degeneration of the substantia nigra and a subsequent drop in neuro-transmitters leading to a breakdown of the functions associated with the basal ganglia. The resulting problems may be rigidity, tremor and slowness of movement (bradykinesia), although drug therapy may also result in involuntary movements that are behaviourally similar to athetosis.

Multiple Sclerosis arises due to a degeneration of the myelin layer in the CNS, the consequences may be visual deficits and problems with limb sensation and muscular weakness. The problems may be first evident in the lower limbs, but upper-limbs are also affected. Once again, although muscular weakness (hypotonicity) is a primary sign, spasticity (hypertonicity) and tremor may also develop.

Generic Features: Hence although we can identify different causal mechanisms in the examples above, the motor system response shares the common features of either: hypotonicity, hypertonicity or involuntary movements. The behavioural consequences are muscular weakness, rigidity, tremor, spasticity, athetosis and these can be considered as generic symptoms of motor pathology that undermine skilled action.

We could adopt the view that these are irreversible dysfunctions of the motor system and that the CP or post-CVA individual will never re-attain adequate function in the affected limbs. There is evidence of neuronal plasticity, however, that suggests re-learning should be possible even when there is damage to areas that are associated with a specific function for an intact motor-system. On the general issue of environmental exposure, Schrott (1997) examined the effects of environment and training on brain morphology. Brain weight can be affected by environmental conditions; more specifically most studies show increases in forebrain and cortex. Environmental conditions can alter dimensions of the brain (e.g. thickness, height, length, width) though changes appear to be more dependent on the duration of and the time at which the environmental manipulations are applied (Schrott, 1997). Specific peripheral inputs can affect corresponding central structures in humans. Elbert et al (1995) provided evidence that string player have increased representation of their left hand in the primary somatosensory cortex. Whereas studies with genetically identical animals provide evidence that brain anatomy may be altered by intellectual challenge. What is unclear is how much change can be elicited, the time frame for such changes, and the degree of compensation they provide (Schrott, 1997).

Table 1.

Motor Disorder	**Functional impairment(s)**
Hypotonicity	Muscular weakness, restricted range of movement (RoM), poor velocity control.
Hypertonicity	Severe restriction on RoM, unpredictable muscular contraction, jerky movements
Athetosis/Dyskinesia	Unintended actions, poor kinaesthetic sensitivity
Tremor	Poor stabilization, unreliable positioning, lack of smoothness.

2.2 Why a virtual environment?

If we accept that there is plasticity in the CNS (Nudo and Friel, 1999; Liepert et al, 2000), then there is potential for the motor impaired user to re-attain function if the environmental conditions are conducive to learning. Although progress in motor function ultimately requires a change within the individual, that change is stimulated and fashioned by the information received from the environment. The sensory feedback (visual or haptic) that arises from an action, and the knowledge of goal achievement (or failure), are essential in guiding the re-organisation and re-acquisition of skill. But how can an environment be fashioned to optimise these factors? What tasks, settings and experiences should the patient be exposed to?

Our perspective is that ultimately, the patient needs to pass through stages of re-exploration to identify strategies of control that are effective for their disturbed motor system (Wann and Turnbull, 1993; Wann et al, 1997). These stages can be viewed as constructing a *forward model* for motor control and an *inverse model* for goal achievement (Wann et al , 1997). Following cortical damage the patient/child is faced with both a new mapping between the central nervous system (CNS) and the actuator (e.g. limb, mouth) and a new mapping between a weakened/spastic limb and the environment. A *forward model* represents learning from sensory feedback about the effect on limb movement of specific motor commands. An *inverse model* is an identification of the motor commands required to produce a specific response, hence it requires information about goal achievement in addition to intrinsic feedback. The latter therefore requires a learning environment beyond the level of conventional biofeedback. An optimal learning environment should be one that allows the patient to practise limb movements, while providing rich feedback as to the errors of movement and potentially provides some guidance toward goal achievement. The advantage of computer generated environments for meeting these goals is that the patient can attempt tasks at their chosen pace and the task can be tailored to their individual level of expertise. A VR setting can provide real-time feedback of errors to the patient and provide feedback on range of movement, trajectory straightness, trajectory speed, smoothness and accuracy. What is required are environments that can guide children/patients in attempting to produce more refined movements, and highlight the errors they make, to enable them to recognise the efficacy of their attempts at movement (*Forward Model*) and identify the effective strategies for intended actions (*Inverse Model*).

Embedding the task into a stimulating games format may provide a motivational drive towards the patient engaging in extended practice in a guided-learning setting. Maclean and Pound (2000) propose that giving patients control of their goals may help in motivation. The goals set by rehabilitation staff may be seen as too ambitious or not ambitious enough: "An understanding of all the factors which impinge on motivation will also empower rehabilitation professionals to better cope with the phenomenon of patient disengagement with rehabilitation...and can only have positive effects on patient care" (Maclean and Pound, 2000). It is difficult to predict what will be motivating for a patient coming to terms with major motor dysfunction. Regular contact with therapists and clinicians who show interest in individual progress probably provides the strongest motivation. Embedding therapeutic exercises into a games format cannot be a substitute for this, but can enhance the feeling of goal achievement and progress, even if the goals achieved are relatively minor. Related motivational effects can be observed in adherence to exercise with the normal population (Annesi, 1998) and the growth of feedback systems for exercise machines (heart rate, calories burned) subscribes to a similar theme.

2.3 Feedback and intensity – or When? What? Why?

Winstein (1991) suggested that the knowledge base in motor learning can be used to provide at least partial answers to a number of clinically relevant questions – such as, what kind of feedback is best for motor learning or how often should the therapist provide feedback during a treatment session? It should be noted that this view was based on the assumption that the principles of motor learning for patients with orthopaedic and neurological disorders are similar to those of healthy individuals. Hartveld and Hegarty (1995) proposed that the challenge for both therapists and patients is "to encourage the development of intrinsic feedback cues in order to control more complex tasks and to decrease reliance on feedback equipment, while at the same time providing just enough augmented feedback to maintain motivation and the desired movement pattern". One proposal is to provide the performer, or patient, with control over the form, quantity and timing of feedback, the practice schedule, and the level of assistance. It has been suggested that allowing patients control over the use of assistive devices and feedback may be particularly beneficial (McNevin et al, 2000)

Different options for the type of feedback arise from the research literature, depending on the motor task and end goal. Frequent feedback seems to speed improvement in task performance, but retention and transfer appear to be adversely affected. Other options are; bandwidth feedback where the performer is only given explicit feedback when their performance varies sufficiently from some preset ideal; delayed feedback where a delay is inserted between task completion and feedback presentation; and various distributions of feedback within trails (e.g. faded feedback). Bandwidth feedback appears to aid performance consistency.

Finally there is an issue as to what aspects of the task should be informed by feedback. There is evidence that if a performer's attention is directed to their own movements the execution of automated skills can be disrupted and the learning of new skills degraded (McNevin et al , 2000). Therefore presenting tasks where the performer is rewarded for task achievement without an explicit focus on their movements may be advantageous. This suggests that *feedback* given to performers during practice may be most effective if it directs their attention to the consequences of movement, rather than to the movements themselves.

There is also debate regarding the intensity, or frequency of practice. Is an increase in the intensity of therapy better? The majority of studies examining the value of increased therapy have used a different type of therapy as the additional quotient. This raises the issue of whether it is the additional therapy time, or the additional therapy type, that is of most benefit. There is some evidence that the addition of more time on the same programme may not reap additional gains (Lincoln et al, 1999), but the addition of time with a different programme may be beneficial (Feys et al, 1998; Sunderland et al, 1992). Additionally therapy may only be effective for less severely impaired patients due in part to the stress or inconvenience of the additional load (Parry et al, 1999). In a study of examining the benefits of increase intensity on arm function following stroke ~17% of the participants did not complete the extra treatment, as they could not tolerate the extra treatment (Lincoln et al , 1999).

2.4 Motor learning and the issue of transfer

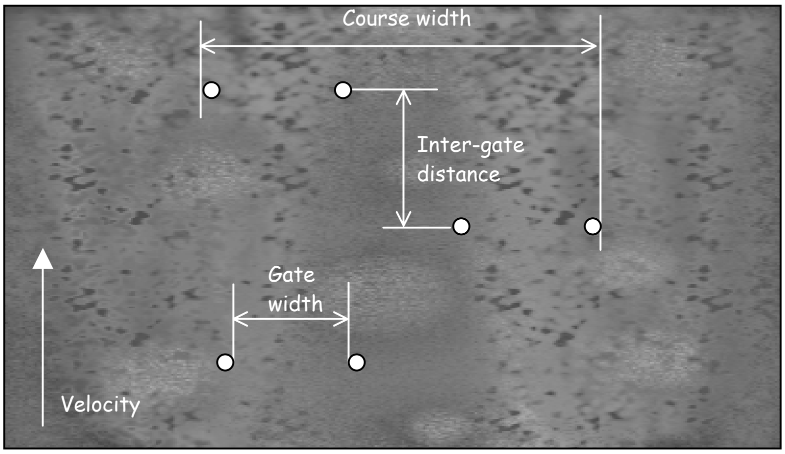
A recurrent issue with the use of virtual environments for training is whether there is likely to be transfer to real world tasks. There is evidence to support the transfer of training in virtual environments to real world environments (Rose et al, 2000; Todorov et al, 1997). Rose et al (2000) also found that training in virtual environments 'was less influenced by the introduction of interfering tasks' compared with real world training. In the case of therapy, there is a general issue as to whether any specific set of exercises will transfer to a functional improvement in activities of daily living (ADL). Although a VE could be used to simulate ADL, there is limited utility in creating the 'virtual kitchen' and 'virtual bathroom'. The major benefit of VE-ADL is at the level of cognitive rehearsal, procedural memory, sequential planning. It is currently not viable to try and simulate the perceptuo-motor consequences of picking up a full teapot. The goal of the VE system should be to breakdown the task, such that simple components of motor control can be practised that will eventually support the challenging task of picking up a real, full teapot. Our approach it to focus on a set of simple motor tasks that address functional problems that arise across a number of cases of motor impairment (Table 1). It is assumed that providing environments that encourage practice on range of movement, speed and smoothness of movement, and anticipation of external forces, will provide the building blocks for more complex skills.

3. THE ARL SYSTEM

With reference to table 1, the aim was to present tasks that progressed from simple goals, such as increasing the range of movement (RoM), to more subtle aspects such as moving through the range smoothly and at speed. We therefore concentrate initially on 4 factors relating to the kinematics of movement: *RoM; End-point accuracy; Speed of movement; Anticipatory timing.* To embed these task parameters within a game environment we have used a slalom-like task where a choice of peripheral input devices may be used to translate the viewpoint left-right in the virtual environment. The viewpoint has fixed velocity during a trial, and the goal of the environment is to pass through as many gates as possible on any given course. Several parameters can be changed within the environment as illustrated in figure 1.

Figure 1. *Changeable parameters within the slalom task.*

Varying the *course width* changes the *RoM* goal for the user, whereas changing the gate width changes the *end-point accuracy* requirement at the extremes of the *RoM*. Increasing the *forward velocity* has the effect of globally scaling the required *response speed*, whereas *inter-gate distance* scales the *timing* requirement. The course layout should be tuned to the capabilities of the patient, but the basic task components generalise to a number of tasks. The current system is being piloted with standard manual input devices such as a joystick,



but also with postural control tasks. In the latter case traversing the environment requires shifting weight between feet, with RoM relating to the percentage weight distribution. The ability to shift the centre of pressure smoothly and accurately between the feet is important for balance and gait. Hence repetitive practice of weight shifting is pertinent for a number of hemiplegic patients. The restriction on activities is primarily due to peripheral input technology. There are still relatively few input devices that are priced at a level suitable for the home therapy sector. When, or if, whole body tracking systems are developed for the games market, it will still be the case that the tasks presented to motor impaired users will need to be broken down into simple achievable sub-goals.

The mapping between input device and the environment is essentially arbitrary. It could be considered that there are two goals: the therapist may have a particular movement goal but there is also a task goal. The task goal may be to translate vertically over a set of obstacles, but the limb/device movement may be a limb rotation. Within the task environment the goals can be considered to have some hierarchical structure:

Level 1: Range of Movement : End-point Accuracy - Course width : Gate width

Level 2: Response Speed : Response Timing - Forward velocity : Inter-gate Distance

Level 3: Working with/against external forces - Terrain gradient

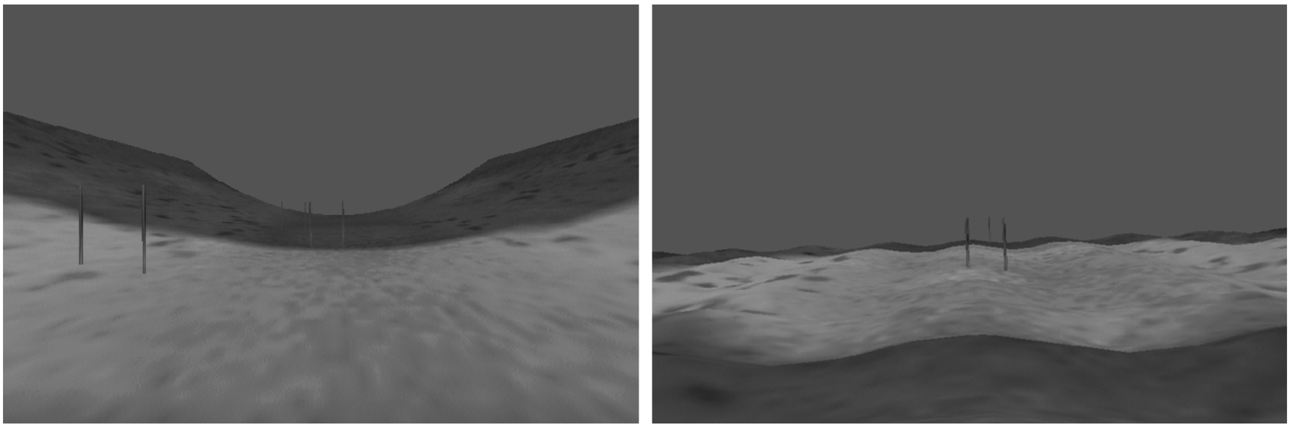


Figure 2. *The slalom task, with force feedback parameters Left: a force-valley Right: an undulating course.*

3.1 Integrating force-control tasks and haptic feedback.

The introduction of low-cost force-feedback joysticks and wheels (e.g. Microsoft Sidewinder, Logitech Wingman) has afforded the potential to introduce force feedback into the system. Within Level 3 we were concerned with providing predictable changes in external forces. To provide a visual correlate of the force field the force-feedback is coupled to changes in the terrain gradient, such that forces act in a direction commensurate with (virtual) gravity. Hence the environment in Figure 2-left requires movement against retarding forces to move upwards to a gate and the control of force-assisted motion away from the gate. This introduces a timing requirement in addition to that proposed in the preceding level. Level 2 introduces a requirement to anticipate the arrival of each gate and initiate an appropriate response. In Level 3 the user should anticipate that there are forces that may assist and resist a movement and in the case of Fig 2-left these switch mid-way through the trajectory. Maintaining a smooth and accurate trajectory in such circumstances requires anticipation and appropriate motor planning. Figure 2-right displays a challenging terrain that requires stabilisation against disruptive forces while moving between spatial targets.

3.2 Tuning the system

We can classify a system by the level of flexibility presented at the user interface. The least flexible system has a fixed interface that may be optimal for an 'ideal user' envisaged by the designer, but awkward or unusable for someone with differing abilities. *Customisable systems* offer the ability to modify the interface to suit the current user. *Adaptive systems* automatically alter aspects of the system to suit the requirements of individual, or groups of, users and their changing needs over time (Benyon and Murray, 1993). In order for a system to adapt sensibly to individual users, a model of the user is required. The system can gain knowledge about the user explicitly, or by monitoring user performance in a suitable task.

Given knowledge of the user there is the choice of either adapting the input to action mapping or the layout of the environment itself. For instance, in the case of restricted movement we can either increase the input gain or decrease the distance between targets within the environment. Changing the environment, rather than input-action mappings, may have the advantage that in-task adaptations may appear more seamless: two targets further apart rather than an increased gain in input should appear more natural. Information for tuning the system is recorded within three distinct models:

User Model: Holds knowledge about the user, either explicitly or implicitly encoded, which is used by the system to improve the interaction. This may be with co-operative agreement with the user, involving the patient in setting his or her own goals.

Domain Model: Defines the aspects of the application that can be adapted or which are otherwise required for the operation of the adapted system.

Interaction Model: (i) Captures the appropriate raw data and records aspects of the individual user's observed behaviour. (ii) Represents the inferences that can be made, adaptations which the system can accomplish, and evaluations of the interaction which are possible.

Table 2. *A simple example of possible model values.*

User Model	Domain Model	Interaction Model
Range of movement	Course width	Outside gates missed ⇒ narrow course if user path did not approach the outer limits of the course

The adaptive component of the system records initial user performance and updates task goals within a level on the basis of user performance across blocks of trials. The size of training blocks and the frequency of update depends upon the practice schedule and specific aims of the therapy programme. At this level some degree of supervisory input from the therapist is essential, to make executive decisions, regarding schedule of practice.

3.3 Schedule of practice

The primary goal of the system is to provide the capability for unsupervised practice of simple movements at the appropriate level. There is the need for supervisor decisions on the intensity/duration of practice, task variation and type of feedback:

Current research generally supports the role of fixed repetitive movements, with high frequency feedback during the initial stages of movement (re-)acquisition. There is strong evidence, however, that variable practice is necessary to ensure generalisation of the skill outside of the specific conditions of practice. A reduction in the frequency and specificity of feedback can also increase retention and learning. There is a transition to be made from providing the patient with a simple stable task, where errors are explicitly flagged, to one where the parameters vary within their achievable range across trials, and feedback is less specific to encourage patients to recognise their own errors. The decision regarding the type of practice that is most suitable for a particular patient requires clinical judgement.

Given that the system is in its pilot stage it is also wise to defer the decision regarding the level that a patient should attempt or when a patient should switch levels. The system can provide support for these decisions by providing data regarding: speed, accuracy, and smoothness of movement at each level or practice block. There are two correlated sets of data, user movements and the resulting change within the environment.

4. SUMMARY

We have described a system for the practice of simple movement patterns that should form the building blocks of more complex functional skills. The twin aims were to provide a simple, but motivating, environment for the repetitive practice of motor skills, while at the same time allowing generalisation to a wide range of motor tasks. By structuring a simple set of virtual environment parameters (e.g. the slalom task levels) there are few system constraints on the input movements. The input device used will dictate the interaction between the patient and the application. The same task may be performed with various input devices, dependent upon the patient's abilities and needs. For our trials we have deliberately chosen a manual control task and postural control (weight shifting) task, to pilot the system across the fine-motor, gross-motor dichotomy. A significant problem in this field is that relatively few developments in the academic sector make the transition to rehabilitation units. One of the primary issues is equipment cost and the cost of support. In the UK we are still some way from a 'wired retired society', but the percentage of the retired population with computer and internet access will increase in the next 10 years. This raises the potential for home-based therapy, in a number of areas, where therapists can check practice schedule and performance via remote links. A stumbling block in this scheme is that rehabilitation systems have been viewed as a relatively small commercial market. Hence although there is a wide range of games and fitness aids that allow web-interaction with others, there is relatively little that can be adapted specifically to rehabilitation. In this respect we believe that rehabilitation systems should capitalise upon the advances in games systems rather than try to swim against these trends. By focusing on using DirectX libraries, with standard acceleration, and adaptations of low-cost games (USB) devices we hope to develop a system that is, in principle, portable to any home/hospital PC with reasonable graphics performance.

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Finger character learning system with visual feedback

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ABSTRACT

Many researches proposed many types of Computer Aided Education (CAE) systems for Japanese Sign Language (JSL). However, foregoing CAE systems for JSL have the problems that they cannot give the differences between targets and answers, and way to revise. The authors propose an innovative CAE system for JSL, which gives users visual information to revise their mistakes utilizing Computer Graphics (CG) animation. This paper presents finger character learning system with visual feedback as a prototype system of the proposed CAE system for JSL, a method to recognize finger characters and a way to give the visual information to revise.

1. INTRODUCTION

Recently, the hearing people had much opportunity to communicate with the hearing impaired. However, the hearing people cannot have sufficient communication with the hearing impaired. The main reason is the difference of mother tongue between the hearing people and the hearing impaired. Therefore, to learn the other language each other is essential for smooth communication.

Sign Language is one of the means of communication of the hearing impaired. The hearing impaired, especially the Deaf, always speaks sign languages in their daily life. When we, the hearing people, study sign languages by ourselves, we make use of textbooks in many cases. However, textbooks, which hold some pictures, do not teach us whether we learn the correct signs or not. Therefore, we may learn incorrect signs.

Many researches (Sagawa et al 2000; Terauchi et al 1999) have developed many types of Computer Aided Education (CAE) systems for Japanese Sign Language (JSL). However, foregoing systems for JSL have the same problems. These systems do not give users two important information; the differences between targets and user's answers and the way to revise the mistakes. Critical reason is that to obtain motions of JSL is quite difficult for PC.

To overcome these problems, the authors proposes an innovative CAE system for JSL, which gives its users visual feedback to revise their mistakes by means of Computer Graphics (CG) animation. As the authors developed finger character learning system with visual feedback as a prototype of the CAE system for JSL, this paper presents the concept of finger character learning system. This paper also presents a method to recognize finger character and a method to give the users visual feedback to revise mistakes.

2. CONCEPTUAL DESIGN OF FINGER CHARACTER LEANING SYSTEM

The finger character learning system consists of three components; recognition part, evaluation part and display part.

The recognition part recognizes given hand posture. The system makes use of a glove type motion sensor as input devise to measure user's hand posture. This input device can obtain the many joints angle data. The recognition part utilizes Vector Quantization (VQ) technique to convert the given joints angle data into notation codes.

The evaluation part compares obtained code with target codes, and evaluates differences between these two codes to distinguish the mistakes of given signs.

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The display part lets a user know whether his/her answer is correct or not. When the user made any mistakes, the system gives him/her the visual feedbacks to revise the mistakes via the display part. The visual feedbacks are given to the user by using color and CG animation. Fig.1 shows the conceptual design of finger character learning system.

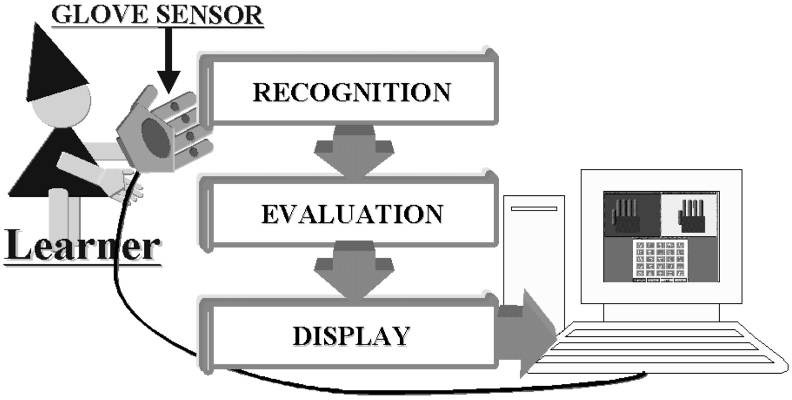


Figure 1. *The conceptual design of finger character learning system.*

3. FINGER CHARACTER RECOGNITION

The system converts given joint data into notation code by means of VQ technique, compares obtained code with target code and recognizes the hand posture of finger character.

3.1 Notation Code System

Most important process of this CAE system is to encode given hand posture of finger character. The foregoing notation code system for motion (Stokoe et al 1971; HamNosys; Kanda 1994, Kurokawa 1994) is divided into two groups, that is, the notation code for sign language and the notation code for whole gestures. However, as the notation code system for sign language tends to use non-alphabetical characters, a computer has difficulty to deal with. Therefore, the authors developed a new notation code system based on Kurokawa notation code system (Kurokawa et al 1992), which use the alphabets to note whole gestures.

A certain hand posture consists of each finger's posture, thumb's posture and their relations. Hence, the proposed notation code system denotes the hand posture as a combination of these factors. Each basic posture has the unique notation code in this system. The relations are denoted as the adduction and abduction between fingers and as contacts between each finger and thumb. Fig.2 shows the example of the proposed notation.

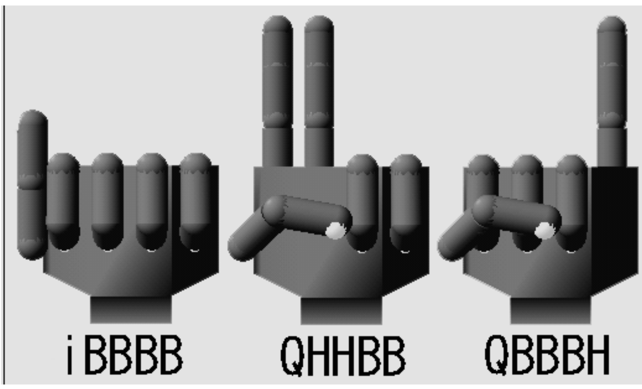


Figure 2. *The example of the proposed notation.*

3.2 Vector Quantisation Technique

The system utilizes VQ technique and converts the given joints angle data into the proposed notation codes. Even hand posture that indicates same character given by single person is variant, not to speak of the one given by another person. The clustering techniques (Cui and Weng 1997; Starner et al 1998) including VQ allow these variations.

The system recognizes the given hand posture of finger character in the following procedure. First, the system prepares the represented quantized vectors in advance. Second, the system converts the obtained joint angle data into sets of vectors. Third, the system determines the best-matched represented quantized vector under the criterion of the shortest Euclid distances. At last, the notation code of selected represented quantized vector is used to denote the given posture. Fig.3 shows the process of notation conversion.

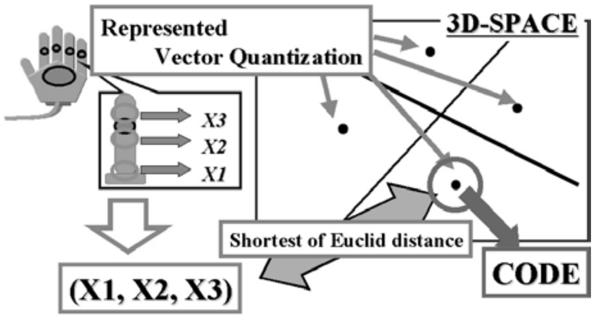


Figure 3. *The notation code generation.*

4. VISUAL FEEDBACKS TO REVISE

The system teaches user's mistakes by means of color and animation. The system compares the obtained code with the target codes, and evaluates the differences. The differences are the user' s mistakes. Fig.4 shows an example. In this example, the third digit is different.

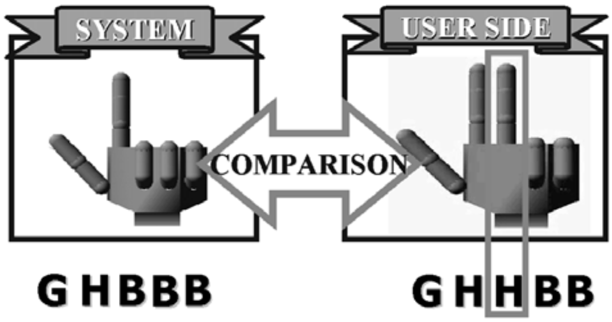


Figure 4. *Example notations.*

The system lets the user know the user's mistaken finger using striking color and gives way to revise the mistakes by CG animation. The system generates CG animation in the following manner. The system regards the obtained finger posture as the first key flame of CG animation and the target finger posture as the second key flame. The CG animation is produced as the interpolation between these two key flames. Fig.5 shows a snapshot of the system output that shows the mistake, and Fig.6 shows the animation.

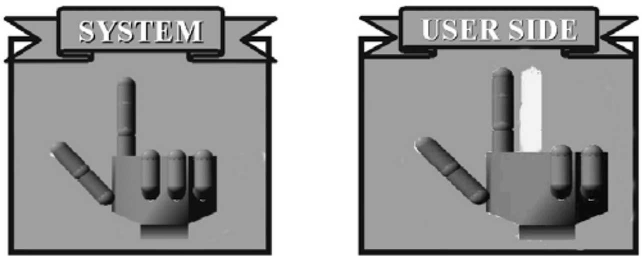


Figure 5. *Visualising a mistake with color change.*

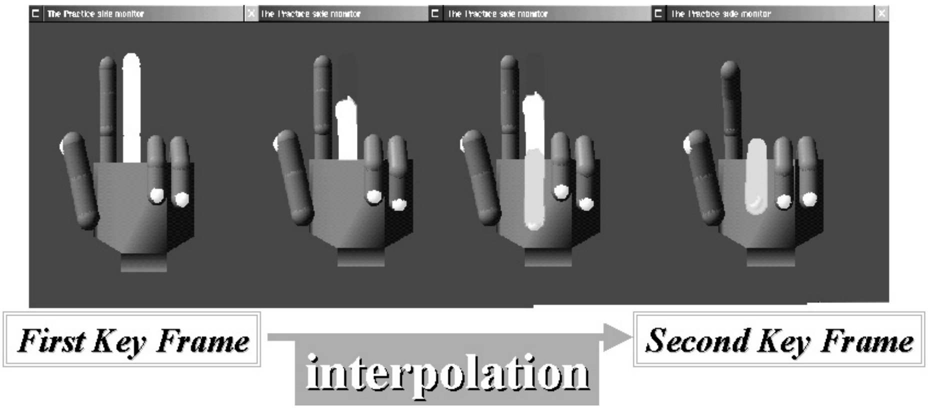


Figure 6. *Visualizing a way to revise using CG animation.*

5. EXPERIMENT

5.1 Experimental purpose

If the proposed concept has advantage in learning finger character, people can learn precise finger characters quickly via the system. Therefore, the authors developed the prototype finger character learning system with visual feedbacks and experimented about the effectiveness of the prototype system.

5.2 Prototyping

Fig.7 shows snapshots of the prototype system. The prototype system utilizes "Cyber Glove TM"(Virtual Technologies 1994). Cyber Glove TM can obtain 18 joints angle of human hand and flexions of wrist.

(a) **(b)**

Figure 7. *The prototype finger character learning system. (a) Overview. (b) Snapshot of the screen.*

5.3 Experimental procedure

The prototype and a textbook were prepared in advance. The textbook has snapshots of target finger character. Ten subjects were divided into two groups. One group, named "book group", studied finger character via the textbook, and the other group, named "system group", studied finger character via the prototype. Each group studied finger character for ten minutes via given method and tried to show all target finger characters by themselves as shown in Fig.8. This procedure repeated three times. Fig.8 shows this experimental procedure.

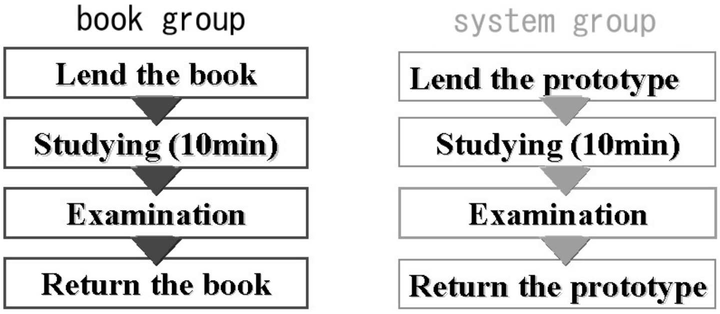


Figure 8. *Experimental procedure*

6. EXPERIMENTAL RESULT AND DISCUSSION

Fig.9 shows the result. The X-axis shows the number of iteration and the Y-axis shows mean accuracy of each group.

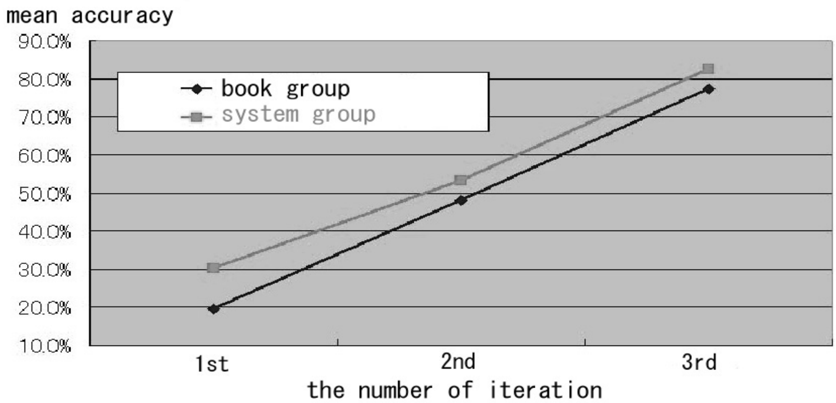
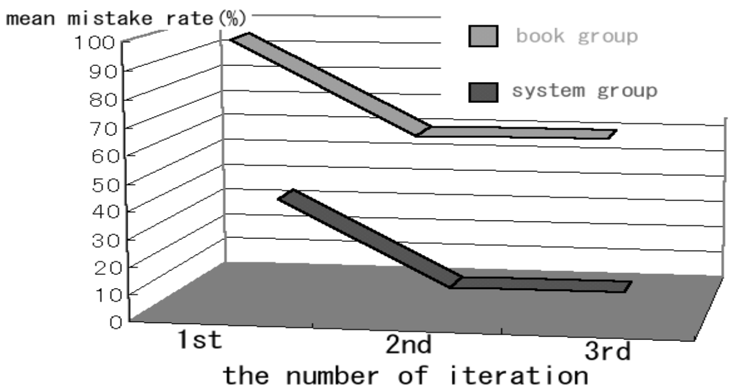
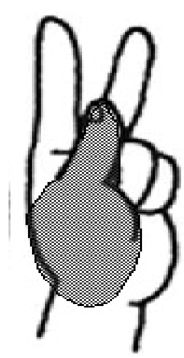


Figure 9. *The experimental result*

The authors examined about the accuracy rates of both groups. Testing statistical hypothesis under 5 % significant level resulted in the significances. The result shows the system group learned finger characters quicker than the book group under the conditions mentioned above. Therefore, the result proves the effectiveness of the prototype system.



(A)



(B)

Figure 10. *A finger character of "KA". (A) Mean mistake rate of each group. (B) Hand posture*

Detailed investigation of the result cleared that there were several characters that the book group could not learn throughout the examination. Finger character "KA", shown in Fig.10, is one example of them.

The result in Fig.10 shows that error of book group was about double of error of system group and the error of book group hardly decreased in three times. Main reason of the result was the lack of contact of thumb's tip.

The typical characteristic of finger character "KA" is that thumb's tip contacts a center of middle finger. On the paper space, to express the contact information like this is difficult. Therefore, the book group can obtain wrong information about finger character "KA". Moreover, subjects in the book group cannot notice their own mistakes and it seems that the book group could not revise the mistakes of finger character "KA". On the other hand, if the system group mistakes the contact of thumb' tip, at first, the prototype system can let the system group's members know thumb's mistake by means of the striking color. Subsequently, the prototype system can teach the system group way to revise mistakes until the system group can learn precise finger character. Thus, the discussion may derive a conclusion that visual feedbacks enabled the error of system group to decrease noticeably as to finger character "KA".

7. CONCLUSIONS

This paper presented finger character learning system with visual feedbacks, which was developed as a prototype of the CAE system for JSL. This paper described the conceptual design of the prototype system, the method to recognize finger character and way to revise user's mistakes by means of color and CG animation. The prototype system was experimented and the result proved the effectiveness of the prototype system.

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Inhabited interfaces: attentive conversational agents that help

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ABSTRACT

We discuss the role of attentive agents in virtual reality interfaces. This discussion is guided by experiences and experiments with a virtual reality environment we designed and implemented. In this environment we have introduced agents, sometimes embodied, with which the users can communicate using different input modalities. These agents provide information or are able to perform certain transactions or they help the user in finding her way in the virtual environment, allowing a mix of user exploration and guidance. Among the input modalities that are considered are speech, natural language, mouse and keyboard and gaze. Output includes natural language, visual speech, changes in the virtual environment, animations and menus. Gradually this environment evolves to an environment where multiple users and agents live and communicate with each other. Apart from offering different input modalities and attentive agents, in the near future we also hope to be able, based on current experiments, to offer suggestions to the users based on preferences obtained from their user profile and their visit history.

1. INTRODUCTION

This paper is a progress report on our research, design and implementation of a virtual reality environment where users/visitors/customers can interact with agents that help them to obtain information, to perform certain transactions and to collaborate with agents in order to get some tasks done. We consider this environment as a laboratory for doing research and experiments on users interacting with agents in multimodal ways, referring to visualized information and making use of knowledge possessed by domain agents, but also by agents that represent other visitors of this environment. As such, we think that our environment can be seen as a laboratory for research on users and user interaction in (electronic) commerce and entertainment environments. Moreover, we expect that despite whatever is said about ubiquitous computation, disappearing computers, etc., especially in the home environment, there will be a growing need for social interfaces that can as well be considered as interest communities, inhabited by domain agents, user agents, friends and relatives, etc., that help, advise, discuss and 'negotiate' on matters that range from how and what to prepare for dinner until how to end a relationship with a boyfriend. Our current experiments include the detection of the user's gaze by agents that inhabit the screen and speech commands for a navigation and guidance agent that helps the user to explore a virtual environment by voice rather than using keyboard and mouse. All these experiments are part of the main goal to construct habitable environments that can be approached using natural interaction techniques.

Whether or not the use of embodied conversational agents is appreciated by users is to a large extent an empirical matter (see Rickenberg and Reeves, 2000, for instance). Much will depend on the quality of the agents and the appropriate use that is made of them. The same applies to the use of such agents in interactions with disabled users. The benefits and drawbacks of high quality natural interactions between virtual agents and disabled users will depend on the kind of disability, the kind of task that the agents are put to and many other factors. If the disabled are hindered in their human-human communication situations than they might encounter the same difficulties in the virtual case. If multiple modes of communication are offered to the user than this may provide alternatives to the common keyboard and mouse input modes or the screen and audio channels that may not be available to the disabled user. The major goal is to introduce these other modes of communication like they are used in face-to-face human interactions as Jacob (1995) advocates. In our experiments we are interested in theoretical issues that concern the modeling of natural interaction as well as in the practical use that can be made of this.

2. BACKGROUND

In Lie et al. (1998) we discussed a natural language dialogue system that offered information about performances in some (existing) theatres and that allowed visitors to make reservations for these performances. The intelligence of this system showed in the pragmatic handling of user utterances in a dialogue. Although the 'linguistic intelligence' was rather poor, the outcome of a linguistic analysis could be given to pragmatic modules which in the majority of cases (assuming 'reasonable' user behavior) could produce system responses that generated acceptable utterances for the user. The general idea behind this system was that users learn how to phrase their questions so that the system produces informative answers. The system prompts can be designed in such a way that users adapt their behavior to the system, the prosody of system utterances (in a spoken dialogue) can invite user's to provide information that they already assumed to be known by the system and, more generally, the system may allow the user to assume and address information available to the system either because that information has been visualized in the dialogue context or because the user may assume that the system employs agents that can start searching for certain information (on WWW). Both aspects – visualization and agents – have been the main topics of further research.

In Nijholt et al. (1998) we reported about embedding our theatre system in a virtual reality environment that allowed visitors to walk around in the theatre, to approach an information desk with an agent (Karin, see Figure 1) with a talking face that is able to address the user in a natural language dialogue about available performances. The theatre has been built according to construction drawings provided by the architects of the building. Visitors can explore this environment, walk from one location to another, ask questions to available agents and objects, click on objects, etc. Karin, the receptionist of the theatre, has a 3-D face that allows simple facial expressions and lip movements that synchronize with a (Dutch) text-to-speech system that mouths the system's utterances to the user. Presently, in our implementation of the system, there is no sophisticated synchronization between the (contents of the) utterances produced by the dialogue manager and corresponding lip movements and facial expressions of the Karin agent. Design considerations that allow an agent to display believable behavior can be found in Nijholt and Hulstijn (2000).

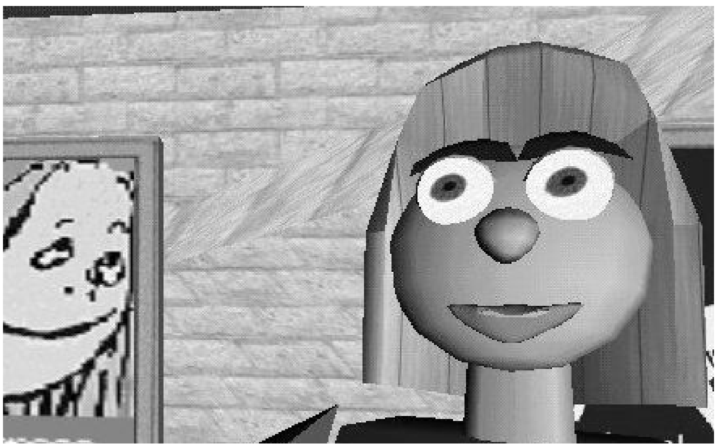

Figure 1. *A close-up of Karin, the virtual receptionist in our virtual environment*

Gradually we have moved from text-based dialogue systems to virtual environments in which the dialogues are embedded in a visual context with embodied agents as conversational partners. Several input and output modes have been added to make the conversations look more like naturally occurring interactions between humans. Below we discuss some of our latest experiments.

3. NATURAL INTERACTIONS WITH AGENTS

The embodied agents in virtual worlds can serve as representations of the user or they can act as autonomous virtual humans. In the first case, there are various means by which users can be represented. Avatars can take the form of simple visual forms or may look like animated characters, possibly resembling the human user (by photographic means). Also the degree in which the user can manipulate the representation can differ a lot. Simple manipulations might be restricted to moving the representation around in the virtual world. With more expressive means of representation, like manipulable faces, the user might be able to change the facial expressions or these may be copied from the natural expressions by the user. Thus also the degree of correspondence in terms of truthfulness between the representation and the represented is an issue in these matters. The avatar functions as a mediator between the user, the virtual world, and possibly other avatars/users in the same world. This means that there are two stages of interactions: between the user seeing/manipulating the avatar and the virtual world and between the avatar and the other users or the virtual environment.

The embodied virtual agents in the virtual world need not be representations of the user but may be autonomous synthetic characters. One aspect of such characters that we are particularly interested in is their capacity to interact with users and other agents; their conversational skills. Because the interaction between them and the user is modeled on the interaction between humans, their success can be judged on the basis of how well they mimic human-human interaction. Another qualitative aspect has to do with the appropriateness of using such agents for specific interface tasks. For certain applications other forms of interaction may be more efficient.

In our projects we are not only interested in the theoretical and implementation issues that are involved in the creation of naturally conversing embodied agents but also in human factors that determine the appropriateness of using such agents in real applications. In order to investigate such aspects we look for ways to make interactions with virtual agents mimic face-to-face (body-to-body) conversations as well as possible, building experimental set-ups. Natural interactions must be modeled as joint-actions in the sense of Clark (1996) using multiple synchronized input/output channels of different modality (sound, vision).

There are a number of reasons why conversations have to be modeled as joint-actions. For one, the production of an utterance by a speaker is only part of a conversation if it is accompanied by perception on the part of the hearer. Secondly, a conversation is made up of a sequence of turns. Participants alternate between speaker and hearer roles. Modeling a conversation simply as a sequence of turns ignores important aspects of a natural conversation. While a listener is attending to the speech by the speaker, he is also continuously providing (back channel) feedback that the speaker perceives and reacts to during his turn, adjusting his production in response to this feedback. This fact is often not taken into account in models and implementations of conversational systems.

Natural, face-to-face conversation between human agents also involves multiple modes of expression. Speech output is accompanied by different types of gestures, facial expressions, body posture and gaze. Current research in multimodal interaction is concerned with modeling these different ways of expressions and their synchronization using animated agents. In the ideal situation these agents should be able to perceive and decode multimodal input from the human user or other agents on the one hand and to produce this type of output convincingly on the other. The common multimedia desktop computer is fluent in providing images and sounds to the user but has only limited and unnatural devices for input (keyboard and mouse). Currently, the conversational agents that people may be familiar with are animated characters that react to typed input only though speech input is becoming more widely available.

In our current environment we have several agents implemented in a Java-based agent framework allowing (primitive) communication between the agents. Moreover, visitors can address these agents. Presently we are experimenting with the DeepMatrix multi-user browser (Reitmayr, 1999), allowing a visitor to see others and to start chat sessions with other visitors. Although this is a nice addition to our present environment, the chat extension does not fit the agent framework, there are separate channels for communicating with system agents and for communicating with other visitors. In the following sections we report about some steps that are taken in order to solve this problem. In general, these can be characterized as follows.

- Redesigning and extending our agent framework such that individual agents can represent (human) visitors (e.g., movements, posture, nonverbal behavior) and can stand for artificial, embodied domain agents that help visitors in the virtual environment (using natural language).
- Designing VRML agents that are controlled through the protocol of the agent framework, that can walk around in the virtual environment (either acting as a domain agent, hence displaying intelligent and autonomous behavior, or representing a visitor and its moving around in the environment).
- Investigations into (and partly discovering) linguistic and dialogue modeling problems that are specific for multiple dialogue partners present in a virtual environment.

In particular we look at two types of studies. The first, described in section 4, addresses our implementations of navigation agents that assist the visitor of the virtual environment. The second type of experiments deals with modeling of gaze behavior in multi-agent conversations (section 5).

4. NAVIGATION

4.1 Navigation Using Speech and Language

Since it turned out that non-professional users have tremendous problems navigating in virtual environments we introduced a navigation agent in our environment, which can be addressed in limited natural language using the keyboard or spoken utterances. Apart from the well-known shortcomings of state of the art speech technology it turned out to be a useful addition. Because of ownership problems of the commercial software that is used (Speech Pearl, Philips) the navigation agent has not yet been included in the publicly accessible websites that have been made available for our system. It is left to the user to choose between interaction modes (speech and keyboard) or to use both, sequentially or simultaneously. In general, a smooth integration of the pointing devices and speech in a virtual environment requires that the system has to resolve deictic references that occur in the interaction. Moreover, the navigation agent should be able to reason (in a modest way) about the geometry of the world in which it moves. The navigation agent knows about the user's coordinates in the virtual world and it has knowledge of the coordinates of a number of objects and locations. This knowledge is necessary when a visitor refers to an object close to the navigation agent in order to have a starting point for a walk in the theatre and when the visitor specifies an object or location as the goal of a route in the environment. The navigation agent is able to determine its position with respect to nearby objects and locations and can compute a walk from this position to a position with coordinates close to the goal of the walk.

In our case, verbal navigation requires that names have to be associated with different parts of the building, objects and agents. Users may use different words to designate them, including references that have to be resolved in a reasoning process. The current agent is able to understand command-like speech or keyboard input. Otherwise it hardly knows how to communicate with a visitor. The phrases to be recognized must contain an action (go to, tell me) and a target (information desk, synthesizer). It tries to recognize the name of a location in the visitor's utterance. When the recognition is successful, the agent guides the visitor to this location. When the visitor's utterance is about performances the navigation agent makes an attempt to contact Karin, the information and transaction agent. In progress is an implementation of the navigation agent (cf. Van Luinen, 2000) in which the navigation agent knows about (or should be able to compute):

- Current position and focus of gaze of the user;
- What is in the eyesight of the visitor;
- Objects and the properties they have;
- Geometric relations between objects and locations;
- Possible walks towards objects and locations;
- Some knowledge of previously visited locations or routes;
- The action it is performing (or has performed)
- Some knowledge of the previous communication with the visitor.

Presently two other approaches are followed in our research on navigation aids in virtual environments. These approaches, unfortunately, have to be followed in different projects. One is the U-WISH (Usability of Web-based Information Services for Hypermedia) project in which we participate as members of the Dutch Telematics Institute and the other is the Jacob project which we do as members of the VR-Valley Foundation, an initiative which aims at establishing a regional knowledge center on virtual reality in the Netherlands. We hope to be able to combine the results of the three approaches in a future design of navigation agents in our virtual environments.

4.2 Navigation in the U-WISH Project

In the U-WISH project (Neerinck et al., 1999) cognitive engineering techniques are used to develop and test support concepts for networked user interfaces and to derive HCI guidelines based on the test results. One of the test services being used in the U-WISH project is the virtual music center. In the context of this project a new agent-based navigation assistant has been built. Rather than exploring the problems associated with addressing such an agent using speech and language, here the emphasis is on the possibility to obtain an evaluation framework in which different kinds of user interfaces can be compared. This required some simplifications on our side, but also some useful extensions, e.g. user profiles.

It is clear that in many situations we can expect different user interaction behavior and different user preferences with respect to the ‘content’ that is offered. These differences follow from different interests, background, culture, intelligence and interaction capabilities of users. These issues can become part of a user profile (obtained by learning, by assuming or by asking), help the system to anticipate the users preferences and even help to guide a user’s avatar acting in the virtual environment. For experimental purposes the user profiles in the U-WISH project are fixed. They just contain a few fields containing, among others, name, profession and interests of a user.

In this project, in the user’s browser we have an ‘eavesdropper’ that listens to the interactions of the user with the virtual environment (our virtual music center) and sends them to the server. For each user the server has an administrator agent that creates (or loads) a user profile, an event history and an advice history. Moreover, it creates a number of sub-agents. Events coming from the client are received by the administrator agent, entered into the event history and then send to an appropriate sub-agent. Responses from a sub-agent are logged in the advice history and send to the client’s virtual music center. For instance, there is a sub-agent called the PositionAgent, which generates responses based on the position (triggered when the user passes a sensor in the virtual environment), the event history and the profile of a user. Similarly, there is a sub-agent called the DialogAgent, which monitors the dialogue with Karin for certain keywords. The responses by these and other possible sub-agents take the form of suggestions to the user, which, at this moment, are displayed, in an advice window. This window may contain text, hyperlinks and internal links to other parts of the virtual environment. The current agents are rule-based, but as long as they comply with the input/output conventions in their communication with the administrator agent more sophisticated agents can be introduced.

During the U-WISH navigation experiments that are now in preparation tasks have to be performed. They are embedded in scenarios about fictive users. Some of the tasks are open (find some general information within a certain limit of time), others are closed (find a specific piece of information). Half of the test participants will be supported by the navigation assistant, the other half not. Results will be presented in a forthcoming paper.

4.3 Navigation in the Jacob project

In the Jacob project (cf. Evers and Nijholt, 2000) we have the task to design an animated agent, which is called Jacob, in virtual reality, which gives instruction to the user. In this project software engineering plays a prominent role. We apply object-oriented techniques, design patterns and software architecture knowledge. In the architecture we have separated the concerns of the 3D visualization from the basic functionality, which follows from a task model, an instruction model and a user model. Presently, the task and instruction model form Jacob’s mind, a control system that observes the world and tries to reach specific objectives by having Jacob perform a certain task (e.g., show the user what to do next) or to produce an utterance to direct the user. Presently Jacob’s task is to teach a user to solve the Towers of Hanoi problem. This is chosen as an example task since we think that the design solutions found there can be generalized very well and when Jacob will be integrated in the virtual music center it can help to navigate through the environment (to teach the user what to do and to find where).

5. IMPLEMENTING GAZE BEHAVIOR AND GAZE DETECTION

Our research into embodied conversational agents is concerned with improving the naturalness and fluency of conversations, addressing a number of issues mentioned above such as the continuity of receiving and producing information in joint interaction and the coordination of different modalities. By defining and implementing different set-ups, using the virtual theatre environment as a basis, we want to achieve insight into the proper modeling of conversations and also measure the effects in terms of user satisfaction.

Several of the projects we are currently engaged in concern the use of a gaze detector in conversations with multiple agents, focusing on the interaction between gaze and turn taking. Seeking or avoiding looking at the face of conversational partners serves a number of functions (Kendon, 1967), one of which involves the regulation of the flow of conversation. Certain patterns in gaze behavior of speaker and hearers that are correlated with turn-taking patterns. For instance, a person tends to look away when beginning to speak and returns to look at the hearer at about the end of utterances or turns. In Vertegaal (1998) such patterns were examined in the context of conversations between a number of human dialogue participants and the implications for representing conversational participants in groupware systems were worked out and implemented in an experimental setting.

In addition to the agent-oriented, the computational linguistic and the dialogue management approaches mentioned above, we are currently working to implement our findings on gaze behavior (Vertegaal et al, 2000) in our environment. That is, the system establishes where the user looks by means of a desk-mounted LC Technologies eye tracking system (http://www.eyegaze.com). In our system multiple conversational agents can be embodied by means of cartoon faces or by using 3D texture-mapped models of humanoid faces. Based on work by Waters and Frisbee (1995), muscle models are used for generating accurate 3D facial expressions. Each agent is capable of detecting whether the user is looking at it, and combines this information with speech data to determine when to speak or listen to the user.

Certain aspects of the structure of the linguistic signal, for instance the topic-focus organization, play another part in gaze and turn-taking behavior during conversations (Torres et al, 1997). At the moment we are investigating how to build agents that know how to behave according to these patterns of natural conversation. To help the user regulate conversations, agents should generate display appropriate gaze behavior. Figure 2 exemplifies this. Here, the agent speaking on the left is the focal point of the user's eye fixations. The right agent observes that the user is looking at the speaker, and signals it does not wish to interrupt by looking at the left agent, rather than the user.

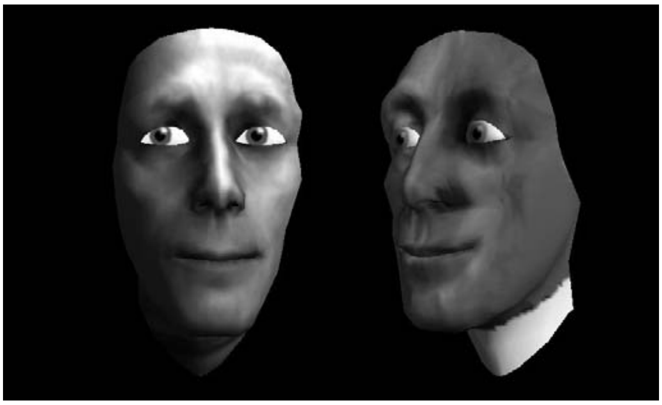

Figure 2. *Gaze behavior experiments with two synthetic agents and a user.*

Our experimental set-up thus consists of two animated talking faces, possibly displayed on two separate screens. The agents can turn their heads and eyes in a number of relevant directions: looking at the user, each other and several other positions. The user's eye-movements are being tracked and the agents are informed about this when their field of vision includes the eyes of the user. Simple conversations will be conducted in which various parameter settings are tested that concern the gaze behavior of the agents, the way in which they and the user take turns in correlation with the informational organization of the utterances they and the user produce. In one of the experiments that will be done in the next months we will have a set-up where we the two agents have related tasks.

A number of variant of this experiment will be carried out. For one version we expect to make an explicit distinction between the information task and the reservation task of our information and transaction agent Karin. Hence, we have a Karin-1 and a Karin-2 who have to communicate with each other (information about user and chosen performance) and with the visitor. Clearly, when during the reservation phase with Karin-2 it turns out that the desired number of tickets is not available or that they are too expensive, it may be necessary to go back to Karin-1 in order to determine an other performance. Although the separation of tasks may look a little artificial, it gives us the opportunity to experiment in the existing environment and with a (modified) existing dialogue system. In other versions the dialogue will be restricted to some canned phrases with variations in timing, turn-taking and gaze behavior of the agents and with variation in the active participation of the individual faces (introducing speakers and silent bystanders). This will provide us with more data on the gaze behavior of users in these virtual settings. Such an experiment will also be used to find out how different emotional factors or personality traits of these synthetic characters can be defined by tweaking the parameters that determine their gaze and turn-taking behavior.

6. CONCLUSIONS

Although originally we didn't intend to build an environment to assist people with disability, we now slowly approach a virtual environment that can be compared with a social setting where different people are ready to help in a conversational way. Obviously, a lot of work has to be done, but recognizing this line of research has been a stimulating attainment. Working towards total communication is not just of theoretical interest may useful to enhance human machine interactions and to bypass the restrictions of the common input-output modes of the stereotypical desktop computer. This is even more true when we move beyond the personal computer. In intelligent environments there is not necessarily a central screen and keyboard. Instead we may expect to have attentive environments where joint voice and gaze information will (unambiguously) activate one or more devices and agents (out of many) in the environment (see Matlock et al., 2000). And from the opposite point of view, agents and devices that try to get our attention by using speech and gaze when necessary.

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Session IX. Enhancing Mobility II

Chair: Andrew Harrison

Wearable computer for the blind – aiming at a pedestrian's intelligent transport system

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ABSTRACT

As contemporary transport systems including the developing Intelligent Transport System (ITS) is vehicle centered, pedestrians – especially elders and persons with disabilities – are always threatened. This paper proposes a new pedestrian-centered traffic system concept named "Pedestrian's ITS" (P-ITS) based on ubiquitous and wearable computing techniques. This paper focuses on the wearable computer for the blind, one of the weakest areas in traffic systems. As knowledge of surroundings is most important for the blind to walk safely, the paper presents a method to support "surrounding presumption" on the wearable computer.

1. INTRODUCTION

The concept of Intelligent Transport Systems (ITS) is first presented in 1996 (Tokuyama et al 1998). ITS is expected to give safer and more convenient environments for drivers through intelligent vehicles communicating with smart way. However, as ITS is vehicle centered concept, ITS benefits few pedestrians, especially so-called "the weak in traffic system" including the elders and the disabilities.

A wearable computer (Sasaki et al 1999) is a portable personal information aid, which enables users to access any kinds of information at anywhere anytime. Therefore, the wearable computers, which are strongly connected with the environments through wireless communication, like CyPhone media phone (Kuutti et al 1999) can realize advanced services for all users.

The paper presents the concept of "Pedestrian's ITS" (P-ITS) (Kuroda 2000). This P-ITS is a system to give safer and more convenient environments for pedestrians, especially the weak in the traffic system, with intelligent walk-aids (wearable computers) communicating with smart way.

P-ITS consists of various components. Especially, wearable computer has wide variation depending on user. This paper focuses on wearable computer for the blind, one of the weakest in traffic system.

The blind faces to many dangers while walking. Therefore, foregoing walk-aids try to give information of surrounding situation as much as it obtains. However, unnecessarily much information confuses user in many cases. This paper introduces the concept of surrounding presumption into walking-aid, and shows the results of the simulation.

2. PEDESTRIAN'S ITS

The basic Infrastructure of ITS is the communication between smart vehicles and smart way. The vehicle and the smart way obtain and exchange the surroundings and their own conditions through innumerable sensors and produce smooth traffic by fitting themselves to the surroundings.

The P-ITS is based on the same framework as shown in Fig. 1. The P-ITS consists of street terminals and the wearable computers and conventional ITS infrastructure. The wearable computers and the street terminals communicate via short-range wireless communication, such as Bluetooth (Bluetooth 2000). The street terminals and the wearable computers obtain the surroundings and its own or user's conditions respectively, and exchanges them each other. The wearable computer navigates the user considering the information from street terminals and itself. On the other hand, the street terminal changes the traffic infrastructure such as traffic lights and moving walks depending on the information given by neighboring wearable computers. Through this configurations, the P-ITS provides some services for smooth and comfortable environment for pedestrians.

The remarkable characteristic of this system is that the total infrastructure is applicable for other commercial and social applications not only for the disabled but also for any people. Therefore, the infrastructure can be realized under commercial requirements.

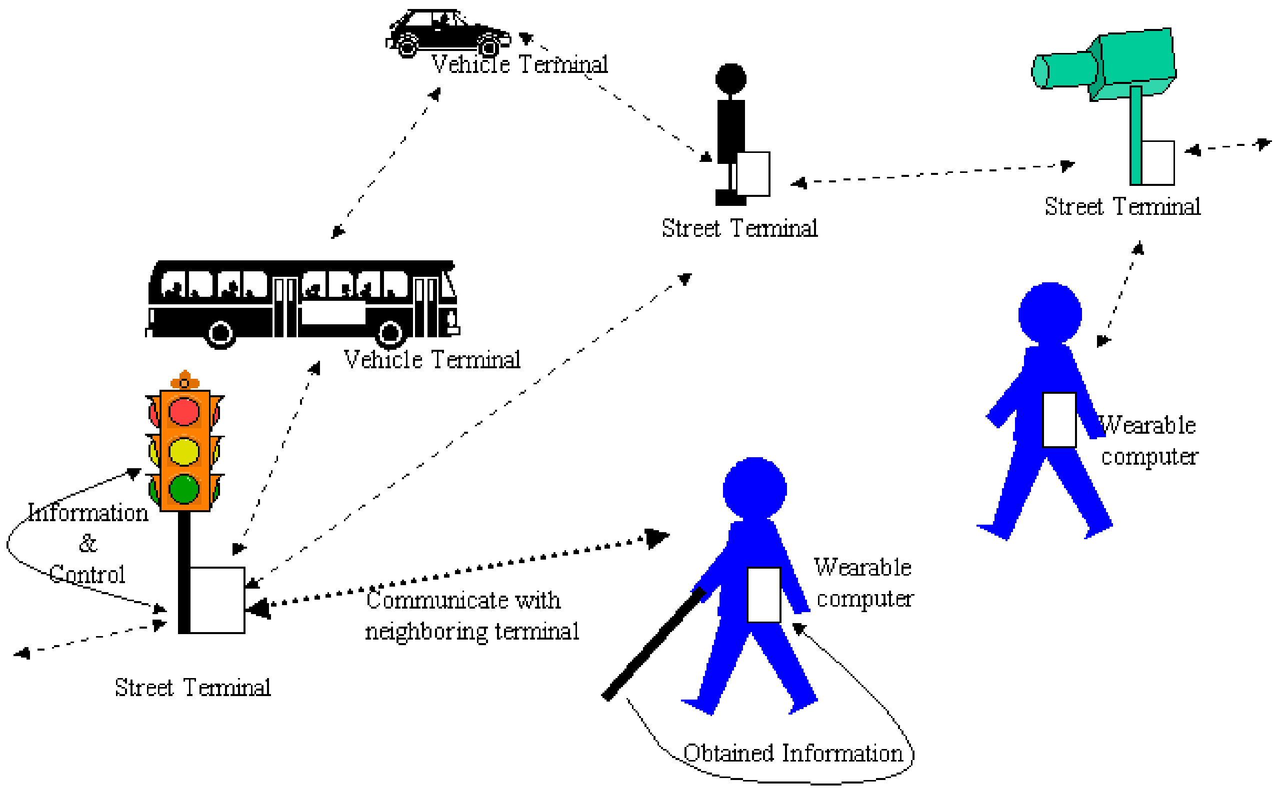

Figure 1. *The Infrastructure for Pedestrian's ITS.*

3. TYPICAL SERVICE MODELS

This section shows three typical service models available under P-ITS infrastructure.

3.1 Expanding "five senses"

The audibly and visionary disabled people, including the elderly people, have a certain amount of difficulties while they are walking, because they may lose fatal information such as noise of approaching car. Therefore, various types of information and walking aid devices are developed. However, ability and sensor range of such devices are hardly limited because the devices realize all sensing, conversion, and display procedures within its portable size body. Nevertheless, the devices are still too big and heavy to wear. Moreover, most of them confuse its user by giving enormous raw data that is just a direct conversion of data obtained by certain sensors.

P-ITS utilizes street terminals with certain sensors, such as CCD cameras or microphones, as external sensors of pedestrian's terminals. This service enables the hearing impaired to know a bicycle or vehicle ringing his/her behind, and the vision impaired to know a obstacles in front of him as shown in Fig. 2. The street terminals around a certain user can provide information, which a single conventional walking aid device cannot. This means that a user can reinforce his/her five senses by wearing a gigantic aggregate of sensors named "city".

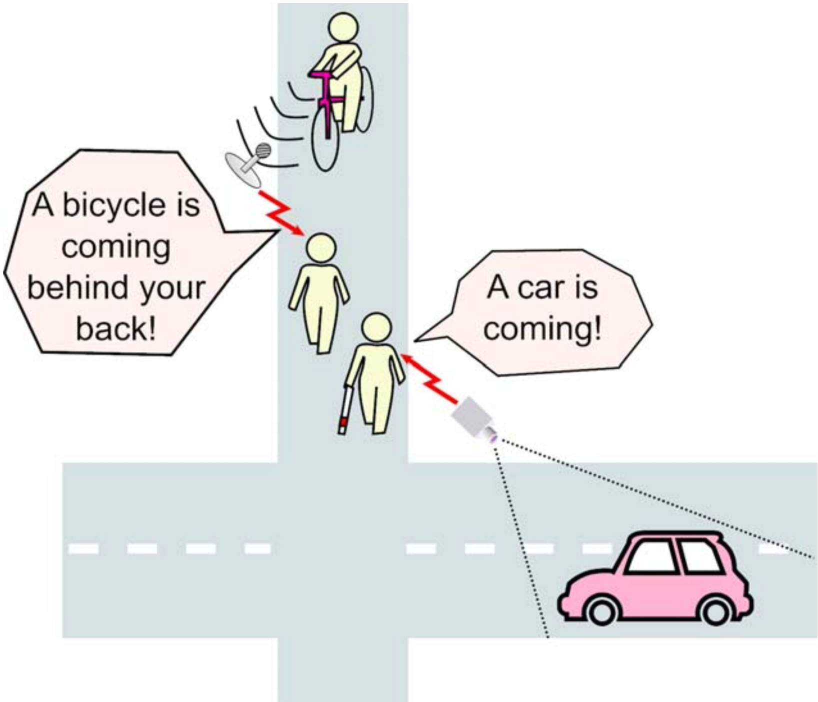

Figure 2. *Expanded "Five Senses".*

When all the street terminals provide obtained information directly to the pedestrian's terminal, the flood of information may confuse user. The street terminals must presume surroundings of the user cooperatively to give necessary and sufficient information to the pedestrian's terminal. This "surrounding presumption" enables the user to pay much attention to other dangers and important affairs for his/her walk by outsourcing a part of presumption process. Additionally, the information from various types of sensors of streets terminals and pedestrian's terminal itself enable advanced circumstantial judgment, which a single pedestrian terminal cannot realize.

P-ITS enables the pedestrian's terminals without many sensors and powerful processor to provide required information by outsourcing the sensing and processing tasks. Hence, the pedestrian's terminal can concentrate its computational power to provide better interface for its user.

3.2 Producing smooth traffic

As developing ITS is vehicle centered system, ITS benefits few pedestrians. In order to provide truly barrier-free walking environment, pedestrian-centered reconstruction of whole traffic system is unavoidable.

Global positioning system (GPS) terminal can navigate its user through barrier-free route, such as the stairs with escalator, and the pavements free from bumps. The extended five senses mentioned above may tell better route, which avoids the crossing over heavy traffics and the crowded sidewalks. However, this approach cannot provide pedestrian-centered traffic system, as it requires the additional efforts of pedestrians.

P-ITS realizes pedestrian-centered traffic system with dynamic control of traffic infrastructure, such as traffic signals or moving walks. For example, a traffic light changes its duration of green light, and a escalator or a moving walk changes its direction when elderly people with difficulty in walk approach as shown in Fig. 3.Among this scenario, the traffic light control is partly realized (Nippon Road 2000).

Additionally, the P-ITS may navigate pedestrians through pedestrian's terminals to realize smooth traffic. For example, a certain pavement can be divided into several routes depending on the walking speed of pedestrians. Like this example, cooperation among terminals may provide better environments for pedestrians.

The "extended five senses" service mentioned in section 3.1 is realized on the passive usage of the P-ITS infrastructure. On the other hand, the "promoting smooth traffic" service provides barrier-free environment and efficient use of the infrastructure through dynamic change of the infrastructure.

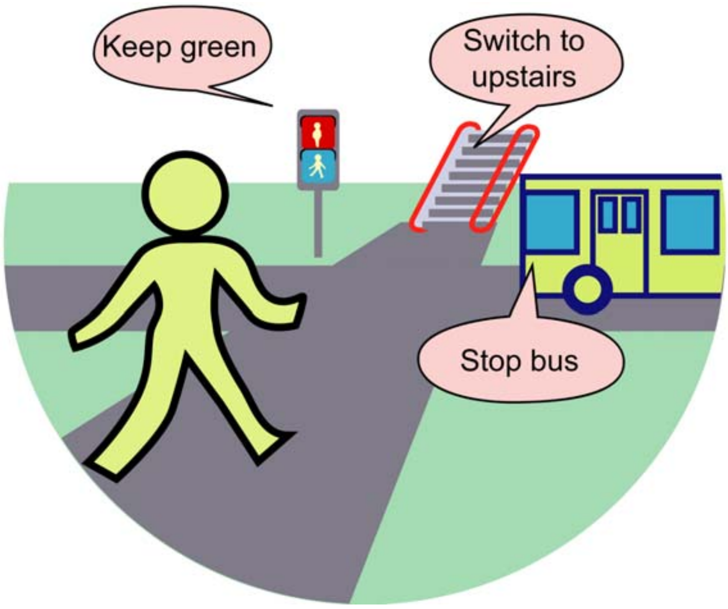

Figure 3. *Smooth Walking Environment.*

3.3 Promoting mutual help

The lack of knowledge sometimes derives rude behavior, and the knowledge may derive warm care.

P-ITS can notify that a person walking in front of your car is the hearing impaired to make you avoid horn crazily and tell the hearing impaired that a car is approaching behind him to make way for your car.

When the pedestrian's terminal knows the ability and situation of its user, P-ITS enables to match the needs between two users. For example, the hearing disabled can meet a person who can translate his/her sign language to English on the streets. It is difficult to realize without the matchmaking service.

4. THE WEARABLE COMPUTER FOR THE BLIND

P-ITS consists of various components. Especially, the wearable computer has wide variation depending on its user. This paper focuses on the wearable computer for the blind, one of the weakest in traffic system.

Japanese law requires the blind to have a cane with them whenever they go out. Therefore, foregoing walking aids with many sensors requires its user to hold two items, that is, the walking aids and a cane. It is troublesome for the user to wear two items appropriately. Additionally, most of foregoing walking aids, which gives the raw data obtained by certain sensors, may confuse its user with the flood of information as mentioned before. This paper proposes to compose all the walking aid into a cane and to give "surrounding presumption" function on the cane-shaped wearable computer (Tateishi et al 2000).

P-ITS provides the surrounding presumption function on the cooperation among street terminals and pedestrian's terminals (wearable computers). However, to provide minimum safety information, a pedestrian's terminal should know its surroundings and presume surroundings with this minimum information.

The most possible danger for the blind is obstacles, which cannot be obtained through a cane, that is, downward gaps and objects, which isn't connected directly to ground like signboards and load-carrying platforms of tracks as shown in Fig. 4. To obtain these obstacles, the wearable computer equips several ultrasound range sensors.

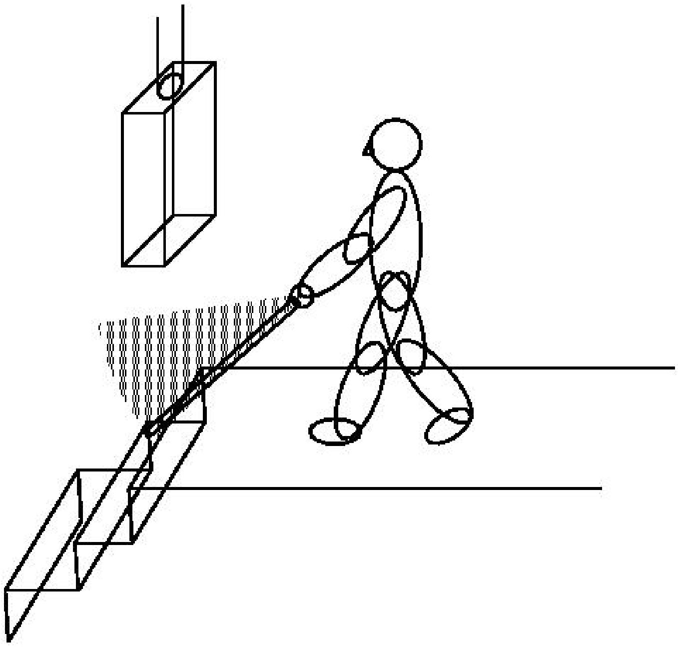

Figure 4. *Obstacles, which cannot be obtained through a cane.*

As a first step, this paper concentrates to obtain the downward gaps. The wearable computer equips three ultrasound range sensors as shown and 6D sensor for surrounding presumption. Ideally, these sensors and processor should be installed in a cane as shown in Fig. 5.

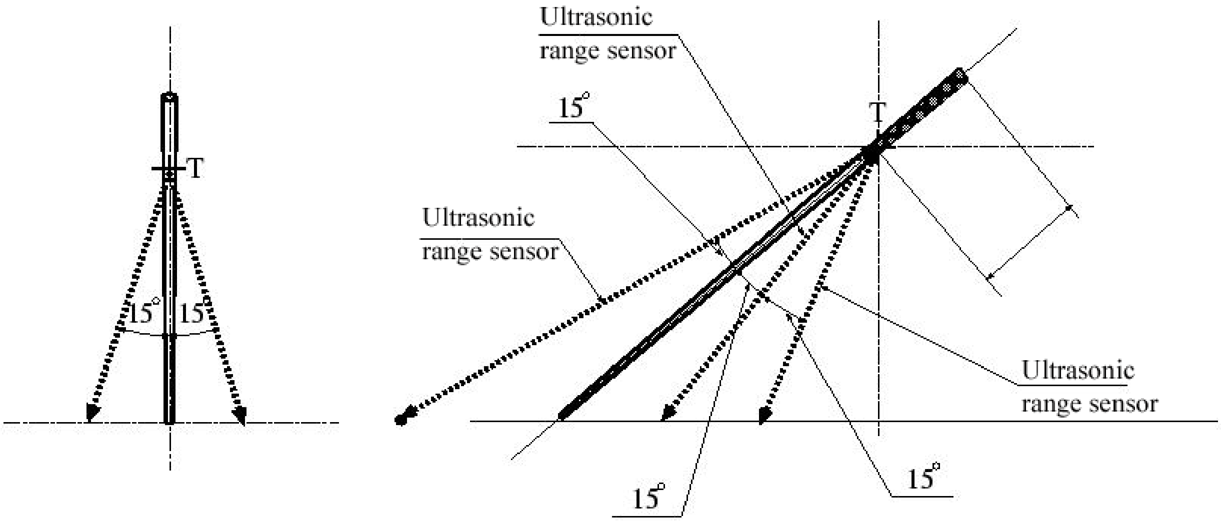

Figure 5. *The sensor configuration of the cane-shaped wearable computer.*

5. SURROUNDINGS PRESUMPTION

To reduce computational task for surroundings presumption is important to make the entire wearable computer compact. The authors developed simple algorithm to obtain 3D map of floor.

The cane can obtain its own position and orientation by 6D sensor, and distances from the grip to certain three points on the floor by ultrasound range sensors. The wearable computer can plot the obtained points into 3D map. The three points give the easy estimation of the floor plane. If the normal vector of the estimated floor plane leans more than a certain threshold, the wearable computer may recognize a slope or gap in front of the user.

However, this estimation cannot tell whether there are a gap or slope. The wearable computer makes additional estimation utilizing the history of the plotted points. The continuous three floor points obtained by a certain sensor *a(i), a(i+1), a(i+2)* give a normal vector of *a(i)* as shown in Fig. 6. If continuing points have similar normal vectors, the points may be on same plane. Hence, the points, which has similar normal vector, form a group. Here, as the two points on the border, *n(i)* and *n(i+1)*, cannot have the appropriate normal vectors, the normal vectors of them is replaced by the normal vector of following point *n(i+2)*.

According to the average normal vector, the wearable computer classifies the groups into two categories, that is, floor and wall. This "floor-wall strategy" enables to retrieve rough 3D map of the floor. Consequently, the system presumes the user's situation whether he is heading a downstairs, a down slope, or a pit. Through this presumption, the system may not give unnecessary information to confuse the user.

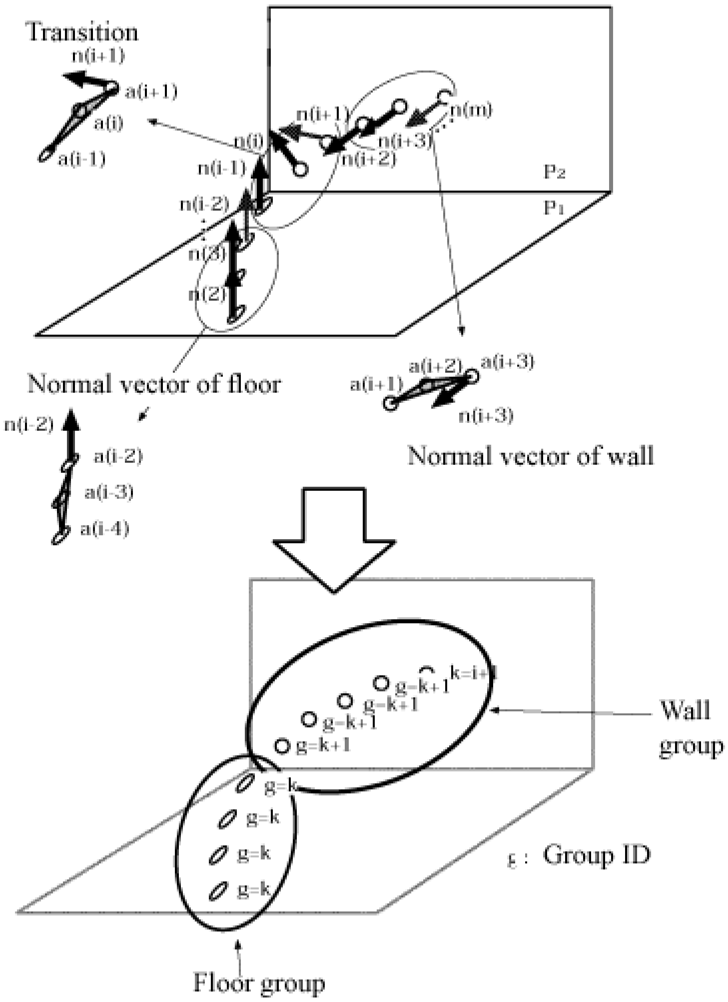

Figure 6. *The floor-wall strategy.*

The VR simulation of this surrounding presumption is performed. Fig. 7 shows a snapshot of the simulation. This simulation clears that the surrounding presumption works properly with small amount of range sensors.

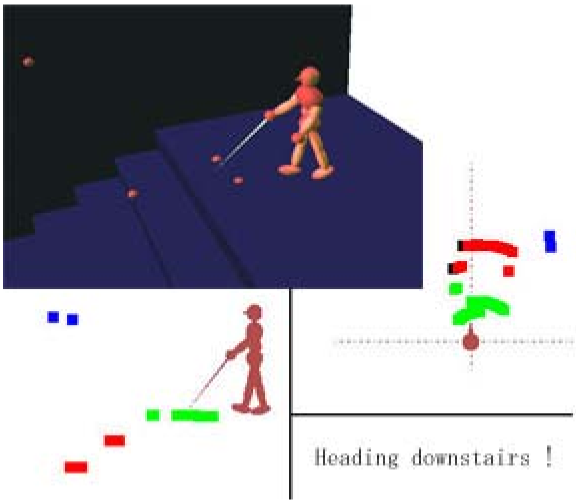

Figure 7. *The simulation result of surroundings presumption for a downstairs.*

6. CONCLUSION

This paper presents the concept of Pedestrian's Intelligent Transportation System (P-ITS). P-ITS provides several services for barrier-free and smooth environments for pedestrians under the cooperation of street terminals and pedestrian's terminals.

This paper introduces the conceptual design of a wearable computer for the blind as one example of pedestrian's terminal. The wearable computer presumes surroundings to provide minimum safety information using several range sensors and a 6D sensor. The simulation clears that a quite simple algorithm enables to presume the situations of the floor in front of the wearable computer.

The authors are continuously developing the P-ITS system including several wearable computers and street terminals equipped with traffic infrastructures such as traffic signals. The authors believes that this continuous development realizes the P-ITS system in a very near future and provides the environment, which makes human beings friendly.

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The effect of interactive virtual environment training on independent safe street crossing of right CVA patients with unilateral spatial neglect

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ABSTRACT

Unilateral spatial neglect is defined as a disorder in which a patient fails to pay attention to stimuli presented to the contralateral side of the lesion; it is known to be associated with decreased functional independence. Our objective was to determine the suitability and feasibility of using a PC-based, non-immersive VR system for training individuals with unilateral spatial neglect to cross streets in a safe and vigilant manner. A virtual environment, consisting of a typical city street, was programmed via Superscape's™ 3D-Webmaster, a 3D web-authoring tool. Twelve subjects, aged 55 to 75 years, participated. Results demonstrated that this virtual environment was suitable in both its cognitive and motor demands for the targeted population. With very few exceptions, the control subjects were able to complete all levels of the program with success. The performance of the patient subjects was considerably more variable, and they were able to complete fewer levels, and usually took more time to do so. The results indicate that the virtual reality training is likely to prove beneficial to people who have difficulty with street crossing.

1. INTRODUCTION

Unilateral spatial neglect (USN) is a phenomenon seen most often in right cerebrovascular accident (CVA) but is also present in patients following traumatic brain injury (Halligan and Marshall, 1993; Lezak, 1995). Neglect is defined as a behavioural disorder in which the patient fails to respond or pay attention to a stimulus presented to the contralateral side of the lesion (Halligan and Marshall, 1993; Heilman et al., 1997). USN has major rehabilitation implications since it is known to be associated with decreased functional independence.

A number of techniques have been suggested as a means for the treatment of unilateral neglect including scanning tasks, right hemisphere activation tasks, visuomotor imagery tasks, self instruction in wheelchair transfer tasks, sustained attention tasks and training awareness of disability tasks (Golisz, 1998; Tham, 1998). One of the basic approaches involves modification of the individual's environment by enhancing stimuli on the left (neglected) side. For example, a colorful band may be worn on the left wrist, brightly coloured food may be placed on the left side of the plate, and red tape may be placed on the wheelchair break mechanism (Golisz, 1998). Another approach is the use of scanning techniques via the use of contrived tasks such as cancellation tasks or natural tasks such as reading or writing. These activities resulted in improvements in the individual's ability to perform a specific task but did not generalize to the performance of other activities. Recent intervention studies include "Sustained attention training using self-talk procedure" (Robertson et al, 1995), "Computerized visual scanning training" (Bergego et al, 1997), "Visuomotor imagery" (Smania et al, 1997), "Contralesional limb activation with 'Neglect Alert Device'" (Roberstson et al, 1998) and "Awareness training influence on motivation for rehabilitation" (Tham & Borell, 1996), all with few cases only. To date, experimental studies have failed to demonstrate the ability of interventions of these types to influence the individual's ability to function well in real life situations.

The apparent inability of traditional tasks to reduce the functional deficit due to neglect led us to consider the use of virtual environments with this population. Due to its unique combination of attributes, this medium has the potential to become an effective, reliable, safe and relatively inexpensive evaluation and treatment tool for the remediation of certain neurological deficits. In particular, its capacity for providing the individual with a sense of presence in and interaction with a simulated yet realistic environment as well as its

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capacity for motivating the user, being presented in a consistent and standardized manner and the clinician's ability to readily grade and modify demands made on the user have the potential to make virtual reality (VR) an extremely powerful tool (Riva et al., 2000). In the specific application discussed here, the safety issue is paramount, as training an individual suffering from unilateral spatial neglect in a real street may be dangerous.

The objective of this initial study was to determine the suitability and feasibility of using a PC-based, non-immersive VR system for training individuals with unilateral spatial neglect to cross streets in a safe and vigilant manner. A successful outcome using a "low-end" VR system would mean that the system would be fully affordable and available to all hospital and community based clinicians.

2. METHODS

2.1 Street crossing Virtual Environment

The virtual environment was programmed via Superscape's™ (3D-Webmaster, a 3D web site development authoring tool. This tool has been in use to develop the virtual soup preparation environment by Christiansen et al. (1998) and the virtual coffeemaker by Davies et al. (1998).

As shown in Figure 1, the street crossing environment consisted of a segment of a typical Israeli city street (signage in both English and Hebrew). An avatar pedestrian, representing the subject, was initially located at the center of the scene facing a crosswalk. Vehicles of different types (e.g., cars, trucks) approached the pedestrian crosswalk from different directions and at different speeds. Subjects were able to control the position of the avatar's head by pressing on one of three large arrows keys (designating head movement in the right, left, and forward) located on the overlay of a programmable keyboard (Intellitools, Inc.). Pressing another key signaled that the subject was ready to commence street crossing, and pressing on either of two red hexagon symbols (also located on the programmable keyboard) caused vehicular travel in the specified direction to stop. The environment was run on a desktop Pentium I computer with a stereo 16 bit sound card and displayed on a 15 inch diameter CRT monitor or projected on a screen via a video projector.

Figure 1. *Screen shot of one level of the street-crossing environment*

2.2 Subjects

Twelve subjects, aged 55 to 75 years, participated during the program development phase of the study. Six of the subjects had sustained a right hemispheric stroke at least 6 weeks prior to the study; four of these six subjects showed clinical signs of left neglect on standard tests. All patient subjects were independently mobile but had difficulty crossing actual streets in a safe or confident manner. The remaining seven subjects were healthy age-matched adults who were independently mobile and had no difficulty in crossing streets. In the experimental phase of the study, currently in progress, an additional 16 patients, aged 40 to 70 years, following right hemispheric stroke who have persistent unilateral spatial neglect (USN), 6-8 weeks since onset are participating. These subjects are also independently mobile but have difficulty in crossing streets in a safe or confident manner. In this phase, the subjects are divided into two equal groups, one that receives VR training via the environment described above and the other that spends a comparable amount of training time with computerized visual scanning tasks.

2.3 Protocol

At the outset, an avatar representing the subject, was located in front of a crosswalk, near the centre of the street. The subject was initially presented with the virtual environment in Stage 1, i.e., a completely controlled configuration. For example, subjects had to look to the left, to the right and to the left again or else the program would not permit the initiation of street crossing. Vehicles approached at low speeds, and cars honked when they approached the crosswalk. In Stage 2, the next level of configuration, the program did not require subjects to look in any particular direction; vehicles approached at low speeds but the approaching vehicle honked only if the figure started to cross the street too soon. In the third configuration, vehicular speed increased by a factor of two. Finally, in the fourth configuration, the direction from which vehicles approached was randomised. Within each configuration, the levels of difficulty were graded from one (e.g., a single vehicle, approaching slowly from the right side of the street, with minimal distracters) to seven (e.g., more vehicles of different colours, moving faster and with additional distracters).

The subject's task was to commence crossing the street (by pointing on the avatar with the mouse) when, in his opinion, it was safe to do so. He was instructed in the use of direction keys for turning the avatar's head to the left, right, or forward in order to see whether vehicles were approaching from either direction. He was also shown which keys to press to cause approaching vehicles to stop moving. If the subject succeeded in safely crossing the street, he automatically progressed to the next level of difficulty. If he caused the avatar to start street crossing when it was not safe to do so, he would see it start to cross the street, and then "experience" an accident. That is, one of the on-coming vehicles would hit the avatar, a screeching brake sound would be heard, and a warning sign with the label "Accident! " would appear. In such a case, the subject was guided verbally by the trainer to increase his awareness of what had occurred. For example, the fact that a car approaching from the left direction had been ignored would be brought to the subject's attention. Subjects were able to repeat each level, or, upon success, continue to the next level. The number of training sessions varied from 1 to 4 sessions, and the duration of each session varied from 30 to 60 minutes.

2.4 Outcome Measures

The severity of unilateral neglect was determined via standardized tests including the Behavioral Inattention Test (Wilson et al, 1987), the Mesulam symbol cancellation (Weintraub & Mesulam, 1987), as well as an ADL neglect checklist (Hartman-Meir and Katz, 1995). In the initial program development phase, the outcome measures focused on the subjects' ability to perform in the virtual environment. These included (1) the frequency, order and direction that subjects searched for on-coming vehicles, (2) the number of trials as well as the total time it took to successfully complete each level, and (3) the highest level successfully completed at the end of training. In addition to these variables, during the experimental phase of the study, the ability of subjects to safely cross a real street was evaluated prior to and following virtual reality training.

3. RESULTS

Results from the initial 12 subjects have demonstrated that this virtual environment is eminently suitable in both its cognitive and motor demands for the targeted population; both the patient and older control subjects had no difficulty in learning how to use the program and in responding to its requirements. Anecdotal evidence, obtained via interviews with each subject following the experiment, indicated that the majority of subjects found the task to be an interesting and stimulating one that had functional relevance to their every day lives.

In Table 1 are presented the total time taken (in minutes and seconds) by each of the program development phase subjects to complete the up to nine different levels of the program. Subjects H1 to H6 were the six age-matched controls and subjects P1 to P6 were the six patient subjects. The age of each subject is listed in the second column. Note that not all of the subjects performed at all levels.

The total time taken to complete the different levels varied dramatically both within and between subjects. For example, the time taken by a typical control subject (H1) varied from 4 minutes, 55 seconds at Level 8 to 29 minutes, 30 seconds at Level 3. In contrast, the total time taken by a typical patient subject varied from 15 minutes, 18 seconds to 45 minutes, 48 seconds. Overall, the total time taken by the control subjects was less than that required by the patient subjects (4:55 to 36:4 min for control group as compared to 16.2 to 45.5 min for the patient group).

As indicated above, if the subject caused the avatar to start street crossing when it was not safe to do so, he would see it start to cross the street, and then an accident would occur. That is, one of the on-coming vehicles would hit the avatar, a screeching brake sound would be heard, and a warning sign with the label "Accident! " would appear. succeeded in safely crossing the street, he automatically progressed to the next level of difficulty.

As shown in Table 2, both the patient and control subjects experienced numerous accidents indicating that the virtual environment presented a significant challenge. In rare cases, for example subject H5 at Level 6, the number of accidents was very great (21), but in most cases, subjects either did not have an accident or they incurred between 1 and 7 accidents before progressing to the next highest level.

It is noteworthy that accident information was used as an indicator of a level's difficulty. Thus, it was immediately evident from our experience with Subjects P1 and P2, that the first two levels were too easy to complete from the point of view of accidents. All subsequent subjects therefore commenced training at Level 3 or higher.

Information concerning the subjects' street-crossing strategies was also documented. For example, the number of times a subject used the arrow keys to look to the left and/or to the right was counted at each level of difficulty. All subjects felt comfortable using these keys, and did no regularly at all levels of difficulty. It would appear that the change in worldview (to the left or to the right) was realistic, and succeeded in providing needed information about the approach of vehicles.

4. DISCUSSION AND CONCLUSIONS

Although the benefits of using virtual reality in training for situations where safety is a factor have been established in defence and industry, there are, to date, relatively few applications in rehabilitation even though its potential for the reduction of distraction for attention disorders and assessment or training of compensatory techniques in the improvement of executive function deficits are acknowledged (Christiansen et al., 1998; Trepagnier, 1999). As demonstrated in the present and other studies, virtual environments provide settings for training and testing that can be controlled by the clinician on one hand and can also simulate realistic field settings on the other (Rushton et al., 1996).

Examples such as an immersive virtual kitchen demonstrate the use of training subjects in meal preparation tasks involving multiple steps (Christiansen et al., 1998)). The study used a prototype computer-simulated virtual environment to assess basic daily living skills (specifically a soup preparing task) in a sample of persons with traumatic brain injury. The study found adequate initial ability to continue development of the environment as an assessment and training prototype for persons with brain injury (Christiansen, et al., 1998).

Another application of immersive VR is a simulated building, represented by a series of rooms of variable shape with entrance and exit doors that are connected by corridors. The objective was to exit the building as quickly as possible. In order to move from one room to the next, subjects had to select a strategy based on given color and shape cues which appeared on the doors. The strategy was changed every seven consecutive right selections. The results encouraged the researchers to continue developing a more advanced prototype (Pugnetti et al., 1995).

In the present study of a street-crossing virtual environment, the results were also indicative of the potential success of simulated settings for various rehabilitation populations. With very few exceptions, given sufficient training time, subjects were able to complete all attempted levels of the program with success. The performance of the patient subjects was considerably more variable than the healthy controls, and they were able to complete fewer levels. On those levels that they did complete, they usually took more time to do so. Overall, the conclusion of the program development phase of the study, based on the time taken to perform at each level, the number of accidents, and the number of times subjects looked to the left and to the right, was that the street-crossing environment provided an appropriately graded setting for training subjects' functional abilities, and one that was perceived as being functionally relevant to an important everyday task.

Based on the performance of subjects during the program development phase, the program has been modified to include an increase in the number of vehicles, randomisation of the spacing between vehicles as well as the direction from which they approach the street crossing, and an increase in the number of distracters (visual and audio). The program is now run with a faster processor (450 MHz) that serves to create a more realistic environment. The preliminary results indicate that the virtual reality training is likely to prove beneficial to people who have difficulty with street crossing including neurological deficits other than stroke and the elderly.

Table 1: *Total time required to complete each level ("-" indicates that subject did not perform at this level).*

Subject	Age (years)	Total Time at each Level (min:sec)								
		Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8	Level 9
P1	65	22:10	34:38	-	-	-	-	-	-	-
P2	67	22:00	20:33	42:00	25:43	-	-	-	-	-
P3	70	-	-	36:25	29:18	26:16	-	-	-	-
P4	72	-	-	16:13	-	30:03	-	-	-	-
P5	62	-	-	-	-	-	22:10	14:36	-	-
P6	75	-	-	39:00	45:48	15:18	28:21	-	-	-
H1	58	-	-	29:30	25:25	18:56	30:50	7:58	4:55	14:18
H2	60	-	-	32:23	22:31	15:15	10:28	-	-	-
H3	61	-	-	21:18	22:46	18:56	9:35	6:05	7:46	15:03
H4	69	-	-	25:10	21:35	14:30	11:00	6:25	6:25	18:05
H5	71	-	-	36:36	25:01	15:55	19:10	8:28	7:58	9:01
H6	73	-	-	33:38	25:00	16:53	17:40	22:30	10:08	13:53

Table 2. *Number of accidents in each level ("-" indicates that subject did not perform at this level).*

Subject	Age (years)	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7	Level 8	Level 9
P1	65	0	0	-	-	-	-	-	-	-
P2	67	0	0	3	4	-	-	-	-	-
P3	70	-	-	2	1	7	-	-	-	-
P4	72	-	-	0	-	0	-	-	-	-
P5	62	-	-	-	-	-	7	3	-	-
P6	75	-	-	2	4	5	5	-	-	-
H1	58	-	-	2	0	0	8	3	0	5
H2	60	-	-	0	0	0	0	0	2	0
H3	61	-	-	2	1	0	1	0	0	6
H4	69	-	-	2	1	0	1	0	0	6
H5	71	-	-	5	1	3	21	3	2	0
H6	73	-	-	9	0	1	2	1	0	1

Table 3. *Number of times subject looked to the right (R) or to the left (L) ("-" indicates that subject did not perform at this level).*

Subject	Level 1		Level 2		Level 3		Level 4		Level 5		Level 6		Level 7		Level 8		Level 9	
	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R	L	R
P1	7	3	17	6	-	-	-	-	-	-	-	-	-	-	-	-	-	-
P2	12	9	20	9	44	40	29	28	-	-	-	-	-	-	-	-	-	-
P3	-	-	-	-	15	11	23	12	27	13	-	-	-	-	-	-	-	-
P4	-	-	-	-	15	12	-	-	-	-	-	-	-	-	-	-	-	-
P5	-	-	-	-	-	-	-	-	-	-	23	18	9	9	-	-	-	-
P6	-	-	-	-	28	15	39	24	36	24	31	12	-	-	-	-	-	-
H1	-	-	-	-	11	11	13	16	13	10	15	15	11	10	4	2	13	8
H2	-	-	-	-	16	9	7	5	6	7	5	3	-	-	-	-	-	-
H3	-	-	-	-	13	15	13	10	11	9	7	7	6	7	9	9	11	14
H4	-	-	-	-	22	28	22	13	12	13	6	7	10	7	7	6	17	15
H5	-	-	-	-	28	15	24	9	19	5	13	2	11	3	9	5	11	5
H6	-	-	-	-	32	43	43	42	41	38	39	26	70	34	22	19	37	46

To date, one control and one experimental subject have completed all training and testing. Based on our experience with the program development phase the following changes and additions were made to the experimental protocol:

- The ability of subjects to cross a busy street is explicitly tested (and recorded on videotape) prior to and following virtual reality and control training;
- The number of practice sessions prior to the commencement of actual VR training is set as are the number and order of levels;
- The during and timing of training sessions is rigorously controlled;
- All subjects are tested with a 17-inch monitor and there are two training groups (VR versus other non-interactive computer programs).

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Project to prevent mobility-related accidents in elderly and disables

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ABSTRACT

As the elderly and mobility-disabled populations in European countries continue to increase, it is imperative that mobility-related accidents and associated consequences be prevented whenever possible. This multi-modal project is aimed to provide educational, diagnostic and VR rehabilitative approach to prevention of falls in aging.

1. INTRODUCTION

As the elderly and mobility-disabled populations in European countries continue to increase, it is imperative that mobility-related accidents and associated consequences be prevented whenever possible. These events are potentially lethal, have a high social cost, expose victims to social withdrawal and a number of professionals to liability (Hoskin,1998). The risk of mobility-related accidents is frequently determined by the convergence of several factors, some of which are intrinsic to the aging, disability or disease processes, some are disease-specific, but many are environmental (Gill et al, 1998; Sattin et al, 1998). In the last 10 years, a substantial knowledge has been accumulated on the epidemiology of some mobility-related accidents and related consequences among elderly and disabled populations (Cumming, 1998). A variety of preventive programs have been undertaken which have been generally successful in reducing the incidence of falls in groups at risk. Multidisciplinary approaches have shown better results, in keeping with the multidimensionality of the problem and the heterogeneity of the risk profiles of the individuals (Close et al, 1999). Non demented individuals who have never fallen are able to recognize risk factors and acknowledge the importance of prevention programs, but may easily underestimate their personal risk until a fall occurs (Braun, 1998).

A problem with this approach is that it focuses mainly on walking and falls. The concept of mobility is much broader one which encompasses all means allowing direct personal interaction between people. In most civilized countries individuals older than 65 and others with mild mental or even major physical disabilities drive personal cars and utilize other public and personal transportation means (e.g. wheelchairs, bikes, escalators, lifts, underground, trains, buses, …) which are potential sources of injuries not directly related to standing and walking ability strictly defined. What accompanies frequent falls and car crashes, for example, is the inability to recognize one's own physical and behavioral limits while walking and driving, and to make adequate adjustments to one's behavior in order to prevent accidents (Sattin et al, 1998). Furthermore, the psychological consequences of falling or having a car crash may be very similar in terms of restriction of mobility and personal autonomy. The failure to recognize that standing and walking abilities are but one factor in mobility-related problems may explain several negative findings concerning the lack of predictive power of laboratory measures of balance. (Baloh et al, 1998). Even a quite severe impairment of balance does not totally disrupt one's chance of mobility if it is adequately understood and managed. The decline of some specific cognitive abilities such as divided attention, immediate and short-term memory, orientation and planning, and of the ability to sustain adequate alertness on potentially dangerous tasks have been linked to falls and mobility-related accidents in old subjects (Rappaport et al, 1998; Lundin Olsson et al, 1998). Falls and mobility-related accidents in old age and disability can be viewed as the result of

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inadequate consideration of one's own physical and behavioral limits in relation to the momentary environmental conditions. An explicit example is the reported increase in falls and fall-related injuries which occurs during wintertime in certain geographic areas (Levy et al, 1998). Most - if not all – such events could be prevented simply by adequate information, education and simple environmental modification measures. On the other hand, restriction of a person's mobility is frequently the result of psychological factors - fear, avoidance – that emerge after an accident; the victim becomes suddenly aware of his/her own physical or cognitive impairments, even if no serious physical damage was suffered, and reacts by limiting his/her range of movements (Howland et al, 1998). Alternatively, the person may deny the relevance of his/her own limits and continue to expose him/herself (and the others) to dangerous situations until a major accident occur. Hence complex psychological reactions tend to modulate the risk-taking attitude of persons of all ages and probably more so of old people – and directly affect the outcome of the behavioral pattern of mobility.

The pattern of mobility is dependent on the effectiveness of the balance system, the alterations of which are expressed as dizziness and unsteadiness. Balance disorders are more frequent in aged individuals and their determinants are different. There is evidence that aging affects multiple sensory inputs, as well as muscles, joints, and central nervous system ability to perform sensory-motor integration. Old age is characterized by a perturbation at several levels, including the motor and sensory levels (decreases in muscle mass, increases in the threshold of vibratory sensations) and at the cognitive level (memory processes, attention span). Gait instability, especially in old women, may be impaired by a combination of increased body weight and decreased muscle strength.

1.1 Aims of the project

This project aims to develop and test clinical tools and methodologies to improve the prevention of mobility-related accidents and the diagnosis and rehabilitation of the functional impairments that lead to immobility in elderly and disabled subjects. Some of these tools will be produced as virtual reality applications. This technology is not only apt for educational purposes, but also lends itself to improve current laboratory procedures to test balance, orientation, navigation, spatial memory and executive brain functions. The latter have been linked to mobility-related accidents, are frequently impaired in older people and disabled individuals, but can be improved with specific rehabilitation.

Accordingly, this project aims at the design of improved educational tools to prevent the development of immobility in old subjects, diagnostic tools to test vestibular responses in static, dynamic and cognitively demanding conditions that simulate those typical of everyday life and, finally, rehabilitation instruments and protocols which will include the use of VR-based simulation to retrain specific sensorial-motor, cognitive, psychological and behavioral maladaptive responses previously identified during the educational and diagnostic workouts.

2. PHASES OF THE PROJECT

2.1 Information phase

An initial phase will provide adequate background to collect and disseminate information concerning mobility-related risks among elderly and disabled, to select, adapt and use screening instruments to identify individuals at risk for accidents and consequences of inadequate mobility patterns and habits, and to raise public interest concerning the project's aims.

Two meetings have been organized so far to illustrate general practitioners (GP) recent acquisitions on the equilibrium system and equilibrium strategies. The main aspects of vestibular, vascular and neurological diseases associated to falls in elderly have been also discussed.

A specific questionnaire, the Falling Risk Inventory (FRI), has been developed to allow GPs to select subjects at risk for falls. The questionnaire is a self-administered instrument composed by 32 items. Eight items concern life-style issues (e.g. how many hours an individual spends at home), 4 social and affective issues (e.g. if a subject lives alone most of the day), 4 relate to general mobility issues (e.g. difficulties climbing the stairs), 8 general health conditions (e.g. presence of hypertension, diabetes), 4 relate to daily activities (e.g. difficulties taking a bath), and finally 4 the medications (e.g. hypotensive drugs, benzodiazepines, etc.)

2.2 Educational phase

This phase will differentially address individuals who have never experienced a serious mobility-related accident and those who have already had mobility-related accidents without severe and permanent impairment or disability. It will also address care givers, associations, health professionals and institutions dealing with at risk groups including younger citizens with physical or mental disabilities.

During the meetings GPs were instructed to suggest individualised modifications of life style and/or medications, on the basis of the results of the FRI questionnaire.

2.3 Diagnostic phase

Includes both screening and laboratory diagnostic workouts to identify subjects at greater risk and those amenable to enter the rehabilitation phase. This phase again involves the target groups and their care givers, including family physicians, and the already existing diagnostic services. Those who are identified as being at increased risk for mobility-related accidents according to the results of the previous two phases are offered a specific retraining. Subjects who have already been identified by the GPs as at increased risk for falls are offered an objective diagnostic workout to quantify equilibrium disorders:

- Labyrinth tests: Spontaneous, Positional and Head Shaking Nystagmus are carried out according tostandard clinical methodology.
- Orientation Test: the Cranio-Corpo-Graphic Orientation Test (CCG-OT)
- Posturography

2.4 Rehabilitation phase

The primary end users of the rehabilitation protocols will be the elderly (65 yrs. and over) either community dwelling or institutionalised who maintain a level of autonomy and personal mobility compatible with one or more of the activities of the project. The typical end user will be an elder still able to ambulate and engage into some form of social life activity who has never incurred into mobility-related accidents but is limiting his/her overall mobility pattern due to generic physical or psychological complaints. Another typical end-user will be an elderly on preserved physical and mental conditions who has already incurred into a mobility-related accident without reporting major physical consequences, but who is limiting his/her overall mobility pattern due to a negative psychological reaction. Another category of end users will be those institutionalised elderly who can still ambulate independently or are wheelchair bound who frequently fall or get lost and because of this experience a severe limitation of their mobility patterns.

The success of any prevention depends on the efficacy of the tools used to educate, to increase the personal awareness and the personal relevance of the message, and the long term maintenance of the behavioral adjustments which have been suggested as the most appropriate and which have been trained. Highly effective education can be given using up-to-date information technology such as virtual reality (VR). The superiority of VR as compared to traditional educational and rehabilitation tools is based on rather well-understood factors such as physical and psychological involvement – known as "presence" – free interaction, and build up of knowledge as a result of direct experience with information presented in precisely contextualised ways, yet modifiable and adapted to the individual's level of comprehension (Lewis, 1998). Because mobility aims to overcome the effect of spatial and temporal distances on human activities and social interaction, it is a highly contextualised activity and its patterns depend on the environment as well as on other factors such as previous experience, availability of transportation means, weather conditions, time limitations, physical and other types of resources. A number of research teams all around the world are producing scientific evidence that learning is not only possible in VR, but it is also cot-effective, well accepted and motivating (Rizzo et al, 1997).

The use of VR applications of the immersive type (IVR) have been shown to cause a significant incidence of unwanted physical symptoms during the immersion and of aftereffects (Regan and Price, 1994*)*. Experts agree that the use of non-immersive VR setups is highly advisable when dealing with patients or other disadvantaged individuals. Accordingly, all educational VR applications for this project will be developed to insure maximal diffusion and cost-effectiveness, will run on any standard Windows '98 or better OS version operating PC without any major hardware/software adjustment. A new computerized equipment is being refined to improve the range of dynamic tests of balance for the screening of individuals at risk for falling (Alpini et al, 1998; see also Cattaneo and Cardini, this volume). The equipment will be expanded to control navigation of virtual environments by means of displacements of the center of gravity in a standing position. The range of movements allowed is still limited, but the equipment has successfully passed the first validation studies when used to diagnose patients presenting mild-to-moderate impairments of balance resulting from neurological diseases. It is however still unknown whether it is more effective than visual-feedback posturography and traditional training in static upright position using multi-sensorial movement control when used to retrain patients suffering from disturbed balance.

Italian Sample	**Israeli Sample**

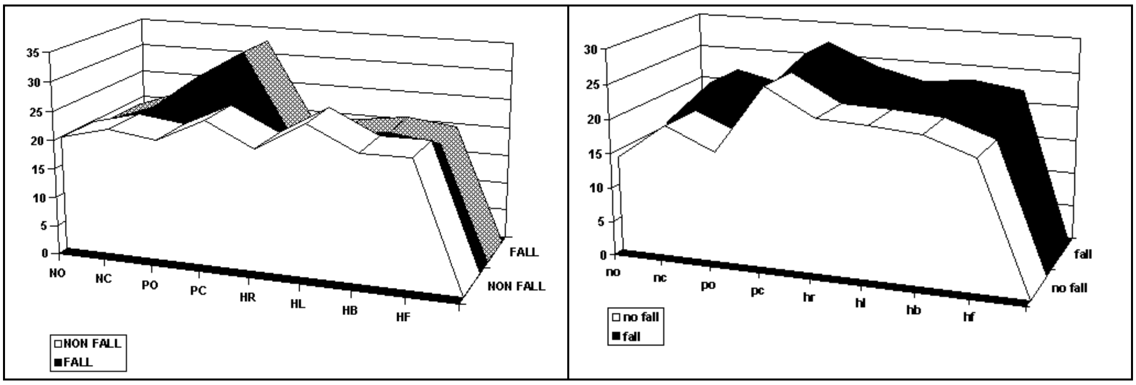

Figure 1a-b. G*eneral stability: falling elderly are less stable than non-falling during standing test on pads. Percent instability index displayed on ordinate (0= normal stability; 100=fall)*

3. METHODOLOGY AND INITIAL RESULTS

3.1 Assessment of orientation

The assessment of orientation relates to the cognitive aspects of the equilibrium function. A typical OT is carried out in a large darkened room where the patient stands blind-folded wearing a walkman with headphones to receive instructions recorded by the examiner and to eliminate external auditory cues. The patient must follow the instructions and perform all the requested movements inside the environment trying to determine his position relative to external points of reference, and to return to the starting position at the end of the test. Then the patient is asked to draw the path on a sheet. By means of this two-phases assessment (guided path and reproduction of it from memory) the most important processes that determine orientation in an environment spatial orientation and spatial memory can be easily evaluated. Initial results have been already published elsewhere (Alpini et al, 1999).

3.2 Posturographic Assessment

The postural control of a standing individual can be partly considered as a dynamic feedback control involving somatosensory, cervical proprioceptive, vestibular and visual information. Measurement of body movements during stance are used to objectively assess postural control, and responses led to the development of posturography. Tetraataxiometry (by Tetrax, Israel) is the last developed posturographic set which consists of two pairs of single piezoelectric sensor platforms that record posturographic heel and toes, right and left applied forces on the ground at the same time.

Posturographic findings of falling and non falling old women belonging to two culturally different populations, the Italian and Israeli, have been compared, and preliminary results are presented here. Twenty-four italian women, aged 73.1± 12.5 yrs., 11 reporting falls and 13 who never fell, and a group 37 israeli women (12 reporting previous falls) of comparable mean age (72.5 yrs) participated. Posturographic measurements have been carried out in 8 different conditions: eyes open (NO for Normal Open); eyes closed (NC for Normal Closed); standing on foam pads (PO for Pads eyes Open) and PC (Pads eyes Closed); bending the head forward (HF) and backward (HB); turning the head left and rightward, HL and HR.

A dedicated software computed different parameters:

1. general stability (ST)
2. Fourier sway frequencies ranging form 0 to over 3Hz and their harmonics derived from spectral analysis and divided into 8 bands (F1 0- 0.10 Hz , F2 0.10-0.25, F3 0.25- 0.35, F4 0.35-0.50, F5 0.50- 0.75, F6 0.75-1.00,F7 1.00-3.00, F8 greater than 3 Hz., along with indices of harmonic distortion.

The main findings are:

1) Falling Subjects are less stable than non falling elderly only when they stand on pads, i.e. they are over-dependent on somato-sensory input and have difficulty to compensate using visual input and/or vestibular control (Fig. 1A and B)
2) In falling subjects, age correlates positively with instability, as may be expected.
3) The Fourier Harmonic Index is lower in falling subjects, which indicates a weaker “systeme postural fin” and probably a weaker postural “feed forward” mechanism, when anticipating dangers which

threaten the equilibrium (Fig. 2 A and B)

4) In non-falling subjects there is no – possibly even a negative - correlation between age and instability. This seems to indicate that a proportion of the elderly - for a hitherto unknown reason - is relatively immune to destabilization, hence to falls (Fig. 3 A and B).

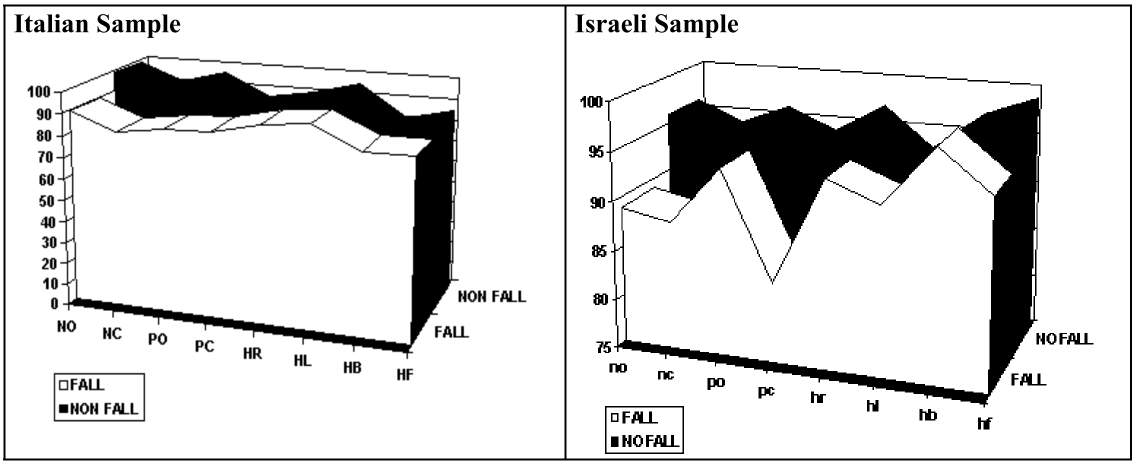

***Figure 2A-B**. Fourier harmonic index. Israeli falling subjects are less stable than non falling controls when the head is bent or turned laterally. Falling subjects show an increase of medium-low sway frequencies as compared to controls which is more evident in Israeli subjects, especially when standing on pads. Percent of max harmonic index displayed on ordinate (100=no harmonic distortion; 0 =max harmonic distortion)*

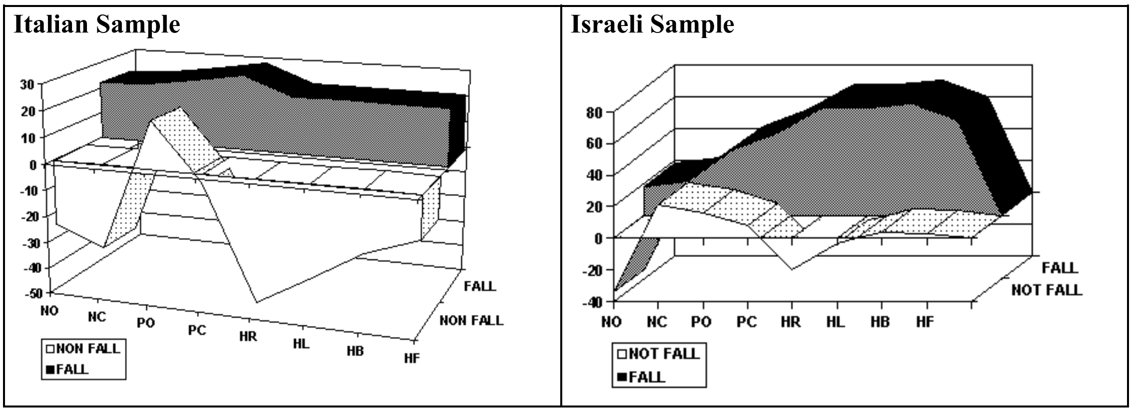

Figure 3A-B. *Correlations between chronological age and stability. Age is correlated to instability only in falling subjects while a paradoxical negative correlation is evident in non-falling subjects, regardless of their nationality. Percent instability index displayed on ordinate (0= normal stability; 100=fall)*

4. CONCLUSIONS

As the project is still in its initial days, we can only draw very preliminary conclusions concerning the activity related to the educational and diagnostic phases:

- The project is based on close collaboration between different specialists and general practitioners.
- The Falls Risk Inventory is a valid tool to select patients with life-style or medical problems making them at increased risk of falls, and to plan individualized programmes aimed at decreasing this threat.
- Tetra-Ataxiometry seems able to identify postural disturbances connected with increased risk of falls and to indentify equilibrium disorders in aged individuals.
- Orientation test is a asimple test to identify cognitive problems that could increase risks of falls.

- Virtual reality will be used in addition to traditional retraining programmes to assist cognitive rehabilitation of falling subjects and to educate subjects at risk.

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Computerized system to improve voluntary control of balance in neurological patients

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ABSTRACT

The treatment of acquired impairments of balance is one of the most elusive problems rehabilitative medicine is facing. Computerized systems to measure how patients control their balance in static conditions have been introduced long ago into clinical practice and proved to be useful; we have designed and developed a computerized system called "BioGP" which combines features of a classic stabilometric platform with those of a retraining device based on visual feedback The aim of this study was to identify homogeneous groups of patients and to provide objective proof of effectiveness for the rehabilitation of patients with balance disorders. The findings confirm that the new equipment provides clinically valid and sensitive information concerning subjects' ability to control voluntary shifts of COP while standing. The information is relevant to VR applications using basically the same approach (Alpini et al., 1998) and are encouraging for possible use of the system as a rehabilitation instrument.

1. INTRODUCTION

The assessment of motor control impose a multivariate analysis on different parameters. A specific assessment is necessary in order to set up an experiment or to plan a rehabilitation program suited to the patients' needs.

(Tesio, 1999) clarify the differences between a classical experiment in biological sciences an experiment carried out in the rehabilitation field. The movements we ask our patients to perform must be assessed by simultaneously detecting different parameters because of the multidimensionality of the task required. Often the variables are not measurable with any degree of precision and the researcher has to use ordinal or nominal data for the statistical analyses (Tesio, 1999). Moreover, important data may not be directly measurable by the therapist (Winter , 1980). Several devices have been developed to describe aspects of motor control (such as posturography or basography) and to collect data not directly available to the rater. Data provided by these devices are not very interesting for the therapist because they do not describe the strategy used by the patient. Improved devices such as the ELITE system for the analysis of gait allow us to better understand how our patients perform a given movement.

Another category of devices have been developed for rehabilitation in different clinical settings; these systems have been called "biofeedback devices". They give to the patient information not directly available to him using visual or auditory stimuli. The first experiences with biofeedback system date back to 1920, when Jacobson was able to produce a relaxation in muscles of anxious patients (Jacobson, 1929). From 1960 on, biofeedback devices have been utilized in different rehabilitation settings, although data on the efficacy of this therapy are often divergent because of different choice of parameters used to defined the problem, different starting hypotheses, or different technical solutions employed. The key point in biofeedback rehabilitation is to make the patient aware of the specific parameter of interest and to make him learn to control it. The control signal provided must be easy to understand, instantaneous and proportional to the variable to be trained.

The system we developed is based on studies on posturometric platform (Guidetti, 1980) and studies on balance in standing position (Alpini and Cesarani ,1999; Winter, 1995). The underlying theory on standing balance from a mechanical point of view consider the body as a rigid mass pivoting about the ankle joints (inverted pendulum theory); the fore-aft oscillation are usually within 8 degrees (Baron 1950). This means that the displacement of the baricentre in a man 1,7 metres high is about 70 millimetres. These oscillations are controlled by the postural system. One must consider that the maximum possible movement exceeds that figure. In fact, the area of stability is almost as wide as the surface defined by the position of the feet on the ground. The control of oscillations exceeding 8 degrees is obtained by a different neural system described by the "projective model " (Droulez et Al, 1986) and is not usually assessed during a normal posturometric examination.

The system called "BioGP" can be considered as a feedback device, as the patient can see his centre of pressure (COP) on the PC screen. The task is to shift the COP along defined paths displayed on the screen. The system can be utilized both for the assessment of postural control and for the retraining of individuals with disorders of balance.

The BioGP used as an assessment device attempts to estimate the "projective model" and to answer some typical therapist's questions: what happens if we ask our patient to move voluntarily his baricentre forward ? Which strategy does the patient use to achieve this goal? Is he able to keep the baricentre in the middle of the feet without swaying? Does he experience more problems when the baricentre is shifted near the toes or near the heels? In a previous paper (Cattaneo et al., 2000) we provided data on the validity and discriminant power of the system. Pilot studies have since been started to verify the effectiveness of the system as retraining device.

2. AIM

The aim of this study was twofold: a) clustering: identify homogeneous groups of patients and b) treatment: to provide objective proof of effectiveness of the rehabilitation of patients with balance disorders. The classification of patients into different clusters allowed us to define treatments based on the main characteristics of each group.

3. PATIENTS AND METHODS

Thirty five adults, 16 males and 19 females, suffering from multiple sclerosis were selected for this study. They were diagnosed as defined or probable multiple sclerosis. Patients showed mild-to-moderate impairments of balance and muscle strength as a result of their illness. We included only individuals meeting the following criteria: walk unaided or with minimal support, able to stand with eyes closed (Romberg position), unimpaired near distance vision and no spontaneous nystagmus.

Patients' balance and limb strength was assessed by rating their performance on the Ataxia Battery Test and on the Motricity index. The main characteristics of the patients' group are presented in Table 1.

Table 1. *Subjects (Evaluation protocol).*

Ataxia battery test: Mean and (Standard Deviation) of Ataxia Battery Test.
Motricity index: : Mean and (Standard Deviation) of Motricity index test; R: right side, L: left side

	N	Age	Male	Female	Ataxia battery test	Motricity index R	Motricity index L
Patients	35	35 (10.1)	16	19	434 (171.1)	94 (7.9)	88 (18.5)

Nine patients were chosen randomly and assigned to a treatment group (15 rehabilitation sessions). The characteristics of this subgroup of patients are reported in table 2.

Table 2. *Subjects (Treatment protocol).*
Ataxia battery test: Mean and (Standard Deviation) of Ataxia Battery Test.
Motricity index: : Mean and (Standard Deviation) of Motricity index test; R: right side, L: left side.

	N	age	Male	Female	Ataxia battery test	Motricity index R	Motricity index L
Patients	9	43.7 (15.1)	5	4	337.3 (252.5)	96.3 (11.3)	83.3 (23.2)

Ataxia battery test: is a widely used clinical test for the assessment of balance during standing and walking (Fregly, 1966). For the statistical analyses we used each subject's total score on the 5 items assessing the ability to maintain balance in static conditions; scores can range between 0 (severely impaired balance) to 900 (excellent balance). The 5 items took on average 25 minutes to complete.

Motricity index: a clinical test of motor loss developed for use after stroke, but useful in any patient suffering from upper motor neuron disease (Wade,1995). The patients were tested while seated on a chair and the procedure took about 10 minutes to complete. Scores ranged from 0 (paralysis) to 100 (normal strength)

The BioGP prototype: The system (Brescia and Mincarone, 1997) is composed by a force platform (Kystler 918 1B), a newly developed amplifier, an A/D converter, and a standard PC with an 17 inch. colour monitor. The actual version of the proprietary software runs under DOS 6.2. The incoming signals from the weight sensors in the platform are A/D converted and processed on-line in order to dynamically display in real time the momentary position of COP on the PC monitor along with its trajectory. Additional summary information such as total time, time spent outside the path, total trace length, relative length, and trace length outside the path is also displayed on the monitor at the end of each single trial (see appendix 1 for a glossary of terms). One horizontal and one vertical virtual paths can be selected for testing the subjects' ability to move the cursor by shifting their COP along X and Z axes (latero-lateral and antero-posterior) while standing on the platform. To personalize the test the software allows one to change the sensitivity (gain) of the feedback (i.e. sensitivity 2,4 means that movement of the cursor is 2,4 bigger than sensivity 1) and the size of the cursor. It is also possible to replay the last tracing off-line and to recalibrate the system if the subject moves his feet on the platform. A specific software has been developed in order to draw new virtual paths to be used for rehabilitation.

Output variables: the system's output consists of numerical variables and graphics. A complete list and description of the variables is reported in appendix 1. Variables can be classified as summary measures - such as RL (relative length) which is the ratio between the length of the trace falling outside the borders of the path and the total trace length and tells whether the subject has been able to travel its COP within the path or not. Other variables assess, for example, if a subject swayed most while descending or ascending a vertical path or if he/she made more exits on the right or the left side of a path.

2.1 Data analysis

Assessment protocol: cluster analysis is performed to classify objects into a small number of groups especially when a priori hypotheses are lacking. An important question is how to organize the observations into meaningful structures. We used two different methods: joining (tree clustering) and K-means clustering. The first method joins object into successive larger clusters; the typical output is the hierarchical tree plot (see Figure. 2). The second method is used when the number of the clusters to end with is already known (usually defined after a joining analysis). After clustering an examination of the means of each cluster and how clusters differ from each other is in order.

2.2 Experimental procedures

2.2.1 Assessment protocol. Subjects were instructed to take off their shoes and to stand on the platform in front of the monitor. The best visual stability was achieved at a distance of 1 meter from the screen (Barnes, 1993). They were shown how the PC was able to display in real time the position of their COP which was represented by a cursor and how they could shift it at will by appropriate body sways. Subjects were then encouraged to practice for a few minutes with the equipment. Then the system was calibrated and subjects were given precise instructions on how to move the cursor along the path displayed on the monitor. In case of a vertical path (Figure. 1), for example, one must first move the cursor down by bending backward and then move the cursor back up by bending forward. All the trials started after the cursor had been placed in the rectangular zone (A). The subjects saw their trajectory as they moved the cursor across the screen. We selected one vertical and one horizontal paths having the same length, width and sensitivity and an additional vertical path with an increased sensivity. To complete the experimental session each subject had to go through the following sequence of tasks: 4 vertical paths with sensitivity 1, rest for 1min., 4 horizontal paths with sensitivity 1, rest for 1min., 4 vertical paths with sensitivity 2.4.

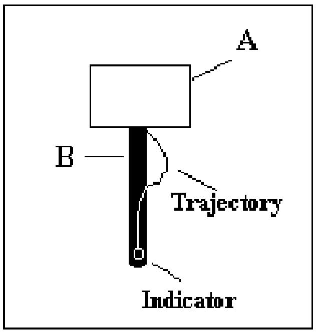
2.2.2. Rehabilitation protocol. Patients were first assessed as described above and then took 12-15 rehabilitation sessions, 2 sessions weekly for a total of 6-7 weeks; each session lasted about 45 minutes. During this period the patients did not receive any other treatment. On each session patients had to complete 7 paths, 3 times each. We assessed the patients' balance score at the beginning and at the end of the treatment with laboratory and clinical tests.

The paths to be used for treatment were selected on the basis of the results of the assessment. Two of the paths were used on every session; the other 5 paths were randomly chosen from the list of all paths selected after the assessment procedures.

4. RESULTS

3.1 Assessment protocol

We report the data obtained from the analysis of V2 path which correlated mostly with the clinical test battery. First we performed the tree-clustering analysis to group patients into progressively larger clusters. The typical result of this analysis is the hierarchical tree (Figure.1). Considering the hierarchical tree plot 3, distinct clusters were identified. The first cluster included only 3 patients, while 18 and 14 patients were grouped into the second and third clusters respectively.



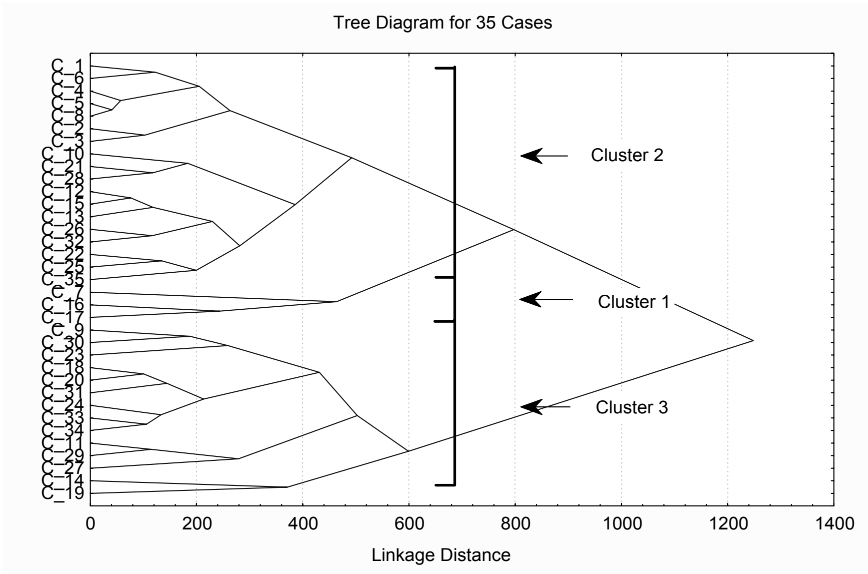


Figure 1. *Vertical Path.* **Figure 2.** *Tree diagram for the 35 cases and 3 clusters.*

As a result we hypothesized that our patients could be grouped into 3 clusters; we tried to cluster variables together in order to verify the differences among the clusters by “K-means cluster analysis”. The qualitative differences among clusters are summarized in Figure 3.

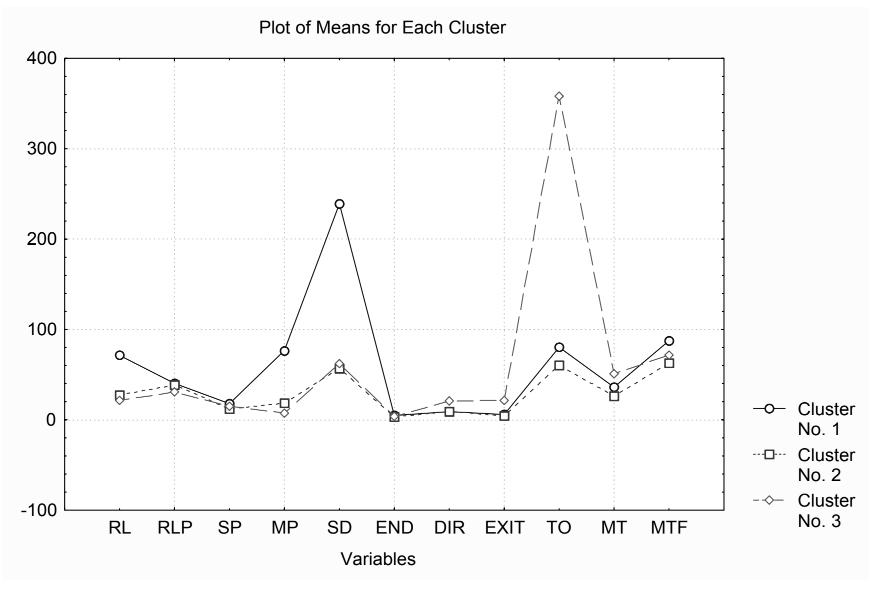


Figure 3. *Differences between the cluster.*

The groups extracted had almost the same cases of tree analysis; only three cases were placed in group 2 instead of group 3. The parameters that best discriminated the three clusters were: RL, SD, EXIT, TO whereas RLP and MTF were the least effective.

3.2 Treatment Protocol

Table 3 shows the experimental data obtained from pre and post treatment evaluations; Table 4 shows the results of the clinical test before and after treatment.

Table 3. *Laboratory data: mean and (standard deviation).*

Parameter	PRE		POST	
RL*	62.5	(16.9)	45.8	(21.2)
SPEED*	17.1	(10)	12.7	(8.1)
SWAY A*	176.9	(72.3)	113.4	(56.2)
SWAY R*	218.5	(162)	145.4	(97.1)

**P<0.01*

Table 4. *Score of Ataxia Battery Test: mean and (standard deviation) (P: 0.8)*

	PRE		POST	
Ataxia B	337.3	(252.5)	343.5	(234.5)

5. CONCLUSION

3.1 Assessment protocol

The cluster analysis identified groups which were quite different one from the other. Cluster 1 had the worst performances: general parameter like RLP showed low values. Patients of this group were not able to keep within the path; the oscillations were 2.4 times wider than the width of the path, and the mean position with respect to the center of the path was outside the boundary. Cluster 3 had the best general parameters: they were able to keep almost always within the path. The patients accomplished their task constantly controlling the position of the CoP, as demonstrated by high Exit and Dir Values (respectively 4 and 3 times more than the other clusters). The problem of this group of patients was the time spent outside the path: they were not able to quickly come back into the path after an exit. Cluster 2 had similar performances to cluster 1, but patients could better control the time spent outside the path.

3.2 Therapeutic protocol

Data obtained from this small group cannot be considered sufficient for final interpretation; also the experimental setting did not completely satisfy the rules of experimental procedure. Data collected showed an improvement of experimental parameters in every patient; the clinical test of 2 patients showed a great improvement while 2 patients had a moderate improvement . The lack of improvement obtained in the other patients can be explained in different ways: Errors in the evaluation of the parameters, number of sessions, paths, poor of sensitivity of clinical tests etc. Another possible explanation is inherent in biofeedback treatments. Patients often improve their skills just in the therapeutical situation and are not able to transfer their knowledge in different contexts. Patients fact should learn to adapt their acquired strategies to the tasks required and also in situations in which the control signal is not directly available but must be extrapolated from other inputs. We define this situation as context dependent learning. Biofeedback rehabilitation and laboratory evaluation have both problems of context . In spite of the accuracy of the data collected, there are some problems regarding the situations in which the patient is placed for assessment. These tests do not usually take into account different contexts in which the movement is usually performed.

Rehabilitation science needs to develop systems that can assess motor tasks in order to obtain reliable information without forcing the patient into situations far from the normal. Rehabilitation devices are needed in order to allow patients to use new strategies in situations normally occurring in everyday life.
Virtual reality could provide a reliable data collection and training protocol in situation that simulate normal environments.

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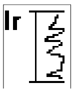
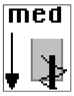
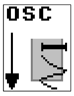
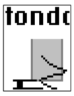
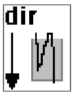
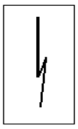
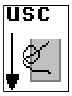
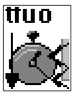
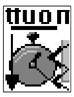
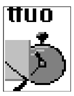
Appendix 1. *Definition of the parameters*

NAME	DEFINITION	CLINICAL MEANING
RL	Ratio between the trace outside the path and the total trace length.	The ability to shift the COP along the path. It is correlated with the ability to control the speed and the direction of movement. It is also correlated with the proper use of ankle strategy.
	**RLP**: the ratio between the total trace length and the path length.	Represents the quality of the performance in terms of energy lost.
	**SP**: speed; average speed (cm/sec)	The speed affects the control of the centre of gravity and the chances to correct a mistake.
	**MP**: mean position; it is the mean position with respect to the axis of the path.	It shows how much weight is shifted on the right or on the left leg. High values of this parameter bring the centre of gravity near one edge of the path.
	**SD: s**way; it is the standard deviation computed as percentage of the path	It tells how much a subject sways. It depends on the subject's ability to detect directional errors very quickly.
	**END**: represents the distance between COP position and the end of the path.	It is small when the subject stops quickly at the end of the path. It requires a good inversion of the muscular strength.
 	**DIR**: the number of times a subject produces a given pattern (combination) of movements (e.g. forward and backward);	It occurs when subjects become aware they are about to make a mistake and correct excessively (overshoot). It happens mostly on the horizontal path.
	**EXIT:** Exits; number of times the subject goes out of the path.	A high number of exits is correlated with a high number of "Dir";
	**TO**: It is the time spent outside the path.	It tells us how many seconds the patient stays outside the right or the left side of the path.
	**MT:** Average time outside; It is the ratio between the time spent outside the path and the variable called Exit	It is an index of reactivity. It tells us if the patient corrects his mistake quickly.
	**MTF:** Time spent outside the end	It tells us the time spent outside the end of the path.

ICDVRAT 2000

Session X. Design of Virtual Environments

Chair: Danaë Stanton

Designing virtual learning environments for people with learning disabilities: usability issues

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ABSTRACT

The Virtual Reality Applications Research Team (VIRART) has been developing communication and experiential Virtual Learning Environments (VLEs) for people with learning disabilities since 1991. As a human-factors-based research group, we have always been aware of usability issues and the importance of consideration of user needs and abilities in any design development process. However, the infancy of VR for use by the general public and lack of VE applications, particularly for special needs users, has meant that there are few examples of usability studies and a general lack of design guidelines. This paper outlines design considerations in development of virtual learning environments and highlights usability issues identified via observation of users with learning disabilities. Specific usability problems were identified relating to communication, navigation and interaction. Examples are given and recommendations for VE design guidelines are suggested.

1. INTRODUCTION

There is a general lack of guidance in terms of how to go about the development of a VE and any specific design principles that should be adhered to (Hix et al., 1999; Wilson, Eastgate, & D'Cruz, In Press). Design rules can be found in the field of Human-Computer-Interaction (HCI) that act as specific instructions intended to be followed by the designer. However, many design rules developed within general HCI are not relevant to virtual environment design because of the different features and objectives of VEs as compared to graphical user interfaces (GUIs) or more traditional computer interfaces (Kaur, Maiden, & Sutcliffe, 1999). The defining features of VR are that a user can freely navigate and interact with objects within a virtual environment in real time. Where these VEs are intended to replicate real world places and activities, there is potential that the user should be able to interact with the virtual environment intuitively, much as they would with the real world (Wilson, 1997). The extent to which this is true will be determined by; the individual (their experience and perception of using VEs), the purpose of the VE (determining any instructions they may have received) and will be shaped by VE design. It has been suggested that by developing a VE that represents reality, providing features common to real world scenarios, such as collision boundaries placed along walls and floors, users will be able to apply knowledge- and skill-based rules acquired in the real world, thus providing a more intuitive experience (Eastgate, Nichols, & D'Cruz, 1997). However, there has been relatively little research conducted to define and evaluate the amount and form of cues required to achieve this.

From the point of view of the VE programmer, decisions concerning amount and quality of objects and interactions constructed within the VE will have a direct impact upon the time required for its development and the speed at which it will run. Wilson et al. (In Press) describe two approaches. One is to model a VE as accurately as possible to its real world counterpart, however, this may result in a VE that is overly complex for its purpose, which could result in slow running speed and unclear cues as to what to do within the VE. The other is to develop a VE containing a crude representation of salient characteristics of the real world. If chosen correctly, this would produce a VE that is meaningful (not necessarily 'realistic') to the user and provides adequate and appropriate cues for interactions required to complete the relevant tasks (Wilson, 1997). However, there is a danger here that this may result in a simplistic VE containing insufficient information or detail for effective application use. The design choice, whether to represent reality, or some abstraction of it, is true for both navigation and interaction. However, defining appropriate levels of VE design complexity is not straightforward.

Recommendations for the design of computer interface systems for users with special needs and learning disabilities include reducing cognitive barriers, simplifying language in task instructions, making displays simple and consistent, providing on-line help and supporting selection techniques (Edwards, 1995). Cress & Goltz (1989) recommend that the visual and audio complexity of the output display should be minimised, and that the system should include on-line memory aids and help screens.

These guidelines, developed for traditional computer interfaces, may not be wholly appropriate for the development of VEs. As already stated, the way in which information is presented within a Virtual Environment is often designed to represent some real world situation and therefore navigation and interaction should be somewhat intuitive and understandable. A VE developed for special needs education, that has been made to look realistic, would probably not provide any additional on-line help. A realistic environment may require a lot of detail and this will not always result in a 'simple' display. Thus, the problem remains; how can we design virtual learning environments with sufficient detail to offer learning of real-life tasks and yet not resulting in complex environments which may be difficult to navigate and interact with?

An evaluation study which examined the effectiveness of VLEs in terms of how well they support constructivist theories of learning in children with learning disabilities (reported in Neale, Brown, Cobb, & Wilson, 1999), reached some conclusions concerning the impact of VLE design on users with learning difficulties:

1. *Use of the virtual environment*

   Use of the virtual environment should be made simpler. Not by oversimplifying its representation, but by subdividing the goals of a given task, to suit the needs of the user.

2. *Interaction*

   Tasks should not be more difficult in VE than the real world. Interaction with a virtual environment is not the same as in the real world and so it is important that the interface doesn't actually make it more difficult, and therefore unusable. This is itself can cause confusion, and lead to misinterpretations.

3. *Efficacy*

   If a VE doesn't convey the real world behaviour in a realistic way, then the students may be picking up the wrong cues and information and make the wrong assumptions about the real world.

4. *Navigation*

   The use of navigation devices can make it difficult to actually move around the VE. Some users find this very difficult and this leads to frustration and some disincentive to use it.

This paper examines the success of these design guidelines as applied to the development of the Virtual City (Brown, Neale, Cobb, & Reynolds, 1999). Further recommendations for the design of virtual learning environments for users with learning disabilities are proposed.

2. USABILITY EVALUATION OF THE VIRTUAL CITY

The Virtual Life Skills project was developed to teach basic life skills to children and adults with severe learning disabilities. This was a community-based project comprising a team of specialists in health care, special needs education, social workers, and representatives of the intended user population, and took a user-centred approach to design and evaluation of the virtual environments. The project, its design and evaluation processes, and virtual environments created have been described in detail elsewhere (Brown, Kerr, & Bayon, 1998; Brown et al., 1999; Cobb, Neale, & Reynolds, 1998; Meakin et al., 1998) and will only be briefly summarised here.

Four components of a 'Virtual City' were completed during this one-year project; a virtual supermarket, a virtual café, a virtual house and a virtual transport system (see Brown et al., 1998). A user group of 16 adults and their support workers specified the contents of each virtual environment and the learning scenarios they wanted in each one (Meakin et al., 1998). The users reviewed the development of the virtual environments and a testing programme involved another group of representative users to 'try out' the virtual city. Evaluation focused on usability (could the users interact with the virtual environments?), enjoyment (did they want to?), learning (demonstration of understanding of skills) and transfer of skills learnt from the virtual environment in to the real world (see Cobb et al., 1998).

Several methods were used for the analysis of usability, producing a form of methodological triangulation to provide richer, more meaningful results than could be obtained from a single data source (Breen, Jenkins, Lindsay, & Smith, 1998). Observational analysis was used to record the levels of support given whilst the user performed tasks in the real world and the equivalent tasks in the virtual environment. Reports of any difficulties faced were also recorded in the form of questionnaires and interviews with both the tester and the support worker.

Each component of the Virtual City was broken down into a number of tasks representing specific learning objectives; each learning objective was then broken down into a list of procedures. Observation checklists consisted of these tasks and sub-tasks, so that problems experienced with certain tasks and specific areas of the VLE could be identified. For example, in the Virtual Café, task 2, 'find a table' could be broken down into a number of basic components:

- Understand instruction 'find a table' – understanding/communication
- Move to table – navigation
- Click on table to sit - interaction

For each task component the level of support provided by the support worker was recorded. This ranged from no support given, through verbal, visual and physical prompts, to support worker does task. The importance of this measure in this situation was that it allowed a comparison between the support given in the VLE and support given to carry out the same task in the real world. If a higher level of support is required in the VLE than the real world, then this may indicate that the task is more difficult to complete in the VLE than the real world and this may be due to the design of the Virtual Environment. It is important to ensure that the training tool used is not more difficult to use than to carry out the task in the real world.

Support workers were asked open-ended questions, allowing them to make comments about each of the task components in the VE with respect to usability and training strategies. Testers, representing the target user population, were also asked questions related to enjoyment and usability of the VE.

3. RESULTS

Usability reports were created for each of the main areas of the Virtual City. The reports combined task information (broken down into basic components) with evaluation results compiled about this task. These included; levels of support required to carry out task, researcher notes, participant and support worker comments and questionnaire answers.

Tables 1 and 2 show example scenarios where difficulties of use were highlighted by the evaluation study. In Table 1 the tasks represent difficulties relating to navigation within the virtual environment and table 2 highlights interaction difficulties. In both cases, the problems encountered were not because the tester did not know what they were expected to do (they had successfully achieved these tasks in the real world trials), but because they could not use the VLE effectively to achieve their goals.

The usability problems experienced from different tasks within the Virtual City were compiled and theme based content analysis was performed (described in Neale & Nichols, In Press) which allows the grouping of similar types of problems experienced across the four sub-components of the Virtual City. This analysis indicated specific usability problems in:

1. *Communication*, specifically in reading text instructions
2. *Navigation*, particularly getting through doorways and other small spaces
3. *Interaction*, a variety of difficulties were identified here including; unnatural interaction metaphors used such as 'bump into table to sit down', users unsure of the effect of actions, difficulty interacting with objects, and insufficient cues provided in the VLE.

Individual usability reports and the content analysis matrix were discussed with a focus group of experts from the fields of human factors, VE development and special needs education and used to make informed decisions regarding design refinements and prioritisation of modifications.

Recommendations for design improvements for each of the usability problems areas are shown in Table 3.

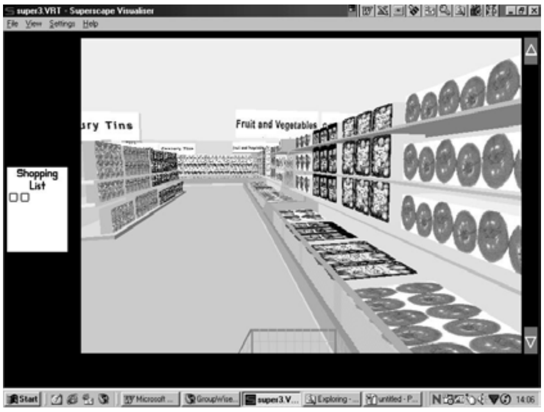

Figure 1. *Enlarged products on shelves.*

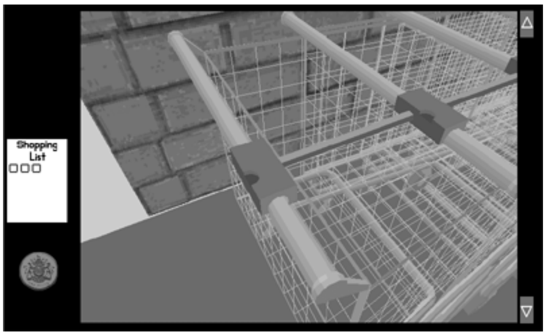

Figure 2. *Fixed viewpoint.*

Figure 3. *Exaggerated size of door and stairway.*

4. DISCUSSION

Constraints from the Virtual Reality System and the Virtual Environment software used means that we may never be able to present a truly 'realistic' experience in a VE. VE designers need to adopt strategies that distort the design so that a realistic appearance is substituted for naturalistic interaction. For example, when representing the shelves in a virtual supermarket to scale, the food on these shelves may appear to the user of a VE to be very small and it may be difficult to differentiate between objects. This is partly due to the users' viewpoint in the VE, they need to be able to see the trolley, the aisle, the shelves etc and all of this must be represented on the screen making each item appear smaller than it would in a real supermarket. To make it easier for users to identify objects within the virtual environment, it may be necessary to make them larger than they would realistically be. Figure 1 shows food in the virtual supermarket larger than it would be in a real supermarket. In the virtual supermarket it is also possible to interact with items that are a long way away. In the real world, when shopping, one may use their peripheral vision and a number of other senses in order to detect the types of items on sale and would walk up close to the shelves in order to examine the items. When using all senses in the real world it is also easy to understand the impact of an action, for example, when picking up an item from the shelf, you will see the item has been moved to your trolley, you will hear the item being picked up, you will feel the item in your hands.

Another way, in which we can design to compensate for the differences between the virtual experience and the real experience, is to set an automatic viewpoint so that the object takes up most of the user's display or to colour the object so that it immediately stands out from its surroundings. In the virtual supermarket an automatic viewpoint was implemented after users had problems locating the area they needed to select. The user must first collect their pound coin, then move towards the shopping trolleys. When the user is close enough to the trolleys they are moved to an automatic viewpoint (shown in figure 2) so that they can see the area where they need to place their coin in order to release the trolley.

When designing a Virtual Environment, it is important to identify its primary objective. In the case that we have described, learning daily life skills, the focus is on teaching procedures required to carry out these skills and providing information about the social and practical consequences of actions (for example, explaining why the bathroom door should be locked and the shower curtain pulled across when the shower is being used). Physical interaction provided by a desktop VR system used with a joystick and mouse as input devices is not representative of the real world. Therefore the aim of the VE is not to simulate and teach physical navigation and interaction with objects, and so these actions should be made as easy to do as possible, and not prevent the user in any way from carrying out procedural tasks.

Again, by distorting the VE to make it less realistic looking we increase the naturalistic experience in the VE. In the case of navigation we found that this was problematic when travelling in and through confined spaces. Figure 3 shows a recently developed VE, which has an enlarged staircase, hallway and doorframes that should make navigation simpler.

5. CONCLUSIONS

VE design and development guidelines provided by previous research studies are by no means comprehensive and the authors themselves recognise that they may not be at all suitable for all types of user groups. They may also be difficult to implement, for example, even if a VE design represents the real world as accurately as possible, the experience may not be perceived by the user in the same way as its real world counterpart, as the VR system will not provide the user with the same sensory powers that they would hold in the real world. The VR system will primarily rely on visual and audio stimuli for communication and the users' visual display will be less detailed with a limited field of view. Therefore it may be useful to build in some exaggeration or manipulation of object and interaction representation in the design of the VE in order to make virtual objects or interaction effects at least as obvious as they appear in the real world. In the cases that have we described, the VE was designed to teach specific life skills, therefore users interact with a series of structured scenarios where attention is drawn to particular objects within the VE. Distortion of reality when representing objects may be necessary in order to make objects appear more obvious when designing for a learning-disabled population. These steps, whilst they may appear contrary to the desire to *replicate* the real world, allow us to *represent* the real world in a way that is still meaningful to the user. Furthermore, these recommendations aim to minimise usability problems and to maximise the potential that VEs offer for learning.

This paper has highlighted usability issues and presented design recommendation appropriate to a specific user population for an application with specific learning objectives. Without further evaluation of usability of these environments, it is difficult to comment upon generalisability of the design guidelines suggested. Further work aims to evaluate usability of these environments on a wider scale and to apply these design guidelines to other user populations using VLEs for different purposes (e.g. social skills training in adults with Asperger's Syndrome, (Parsons et al., 2000)). It is also important for any design guidelines that are developed to be practically useful for VE developers. Considerations as to how they are displayed and information provided would be an essential part of this.

Acknowledgements. We would like to acknowledge all partners and participants in the Virtual Life Skills project, especially the user group and support from the Virtual Reality Applications Research Team at the University of Nottingham.

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Table 1. *Difficulties relating to navigation in the VE.*

Task	Evaluator observation notes	Tester questionnaire	Support worker questionnaire	Coded assistance
Entering supermarket doors	*The view on the screen often makes it difficult to distinguish between the glass doors and glass panels between the doors and the tester sometimes gets frustrated. Support workers often have to provide assistance getting through the door. This is an activity which none of the testers would have a problem with in the real world.*	*Q: What was the most difficult task to do in the supermarket?* *S1: Getting through the supermarket doors*		
Entering bathroom doors	*The doors close automatically. 4 out of 5 testers need no help to do this in the real world, but needed some support to do this in the VLE.*	*Q: What did you not like about using the Café VE?* *S2: Using the toilet and getting stuck in the door* *Q: What was the most difficult task to do in the café?* *S3: Getting through the toilet door*	*"The toilet doors should be made a different colour from the walls - to make it clearer when entering and leaving."* *"The only problem was negotiating these doors."*	Student 101 - more prompts in VE than real world

Table 2. *Difficulties relating to interaction in the VE.*

Task	Evaluator observation notes	Support worker questionnaire	Coded assistance
Locate specific product on shelf	*Difficult to see & identify some items - especially if from a distance or if walking along an aisle and looking at items from a steep angle [they are pasted flat textures]. The tester does not want to stop and turn to look at them at each step - this would take a lot longer - especially if the tester has some difficulties using the joystick.* *Occasions were observed where the product has been mistaken for something else - this did not happen in real life.* *Sometimes support worker required to find the exact location of the product - this did not happen in real world.*	*testers find it difficult to recognise products*	More prompts required in VLE than real world for tester numbers 103, 104, 111, 118 and 120
Put £1 in trolley slot	*"Tester often needs support worker help to click on the trolley slot. These tasks are often frustrating for the user."*		More prompts required in VLE than real world for tester numbers 103 and 104

Table 3. *Recommendations for design improvements.*

Usability category	**Design guideline**	**Recommendation for refinement to VLE design**
Communication	Use a **consistent** format throughout the programme	Display information /instructions using - Audio (have a 'replay' button) - Text (simplified) - Pictures or symbols (in this case Makaton) Standardise symbols and positions on screen for user responses 'yes', 'no', 'move on' and 'replay'
Navigation	Unless the VE is intended to teach navigation skills - **simplify navigation**	- Widen doors, corridors and allow extra space for navigation.
Interaction	Task design should be **realistic,** equally as **complex** as in the real world, and **flexible** (allowing users to carry out sub-tasks in any order). Metaphors used to interact with objects should **reflect** real world behaviour Representation of objects in the VE must be **obvious** Use **set viewpouints** to focus attention to object **Highlight** objects to indicate interactivity	- Include **all** steps and sub-steps of a task. Allow users to carry out **sub-sections** of tasks. Do **not** include any **extra steps**. - E.g. clicking on the menu in the café brings the menu closer to view, representing 'picking up' the menu to read it. - **Enlarge** objects to make them recognisable. - E.g. change view to see coin slot in trolley when close enough - E.g. place a red border around object to be interacted with.

Access to virtual learning environments for people with learning difficulties

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ABSTRACT

An evaluation of virtual learning environments, developed to teach independent living skills to people with learning difficulties, found that individuals differed in the amount of support required to use the input devices. This paper describes the employment of a user-centred design methodology to design, develop and evaluate a virtual environment hardware interface for people with learning difficulties. Central to this methodology is 'usability', a crucial factor in the production of a successful human-computer interface. The completion of this study should result in the production of a virtual environment interface for people with learning difficulties, which satisfies ISO 9241 (the British Standard giving guidance on usability).

1. INTRODUCTION

There have been some interesting developments in the specification of training and education environments for people with special needs, including the Virtual City: a set of virtual environments developed to teach independent living and social skills to people with learning difficulties (The Shepherd School, 1998). In an evaluation of the Virtual City, it was found that individuals differed in the amount of support required to use the input devices: joystick for navigation tasks; mouse for interaction tasks (Cobb et al, 1998). Studies on the most appropriate methods of virtual environment control for people with learning difficulties have been conducted. Hall (1993) concluded that a joystick, limited to two simultaneous degrees of freedom, had the greatest utility in navigation. A further study evaluated a set of interaction and navigation devices, from a range of affordable and robust devices commonly used in special schools (Brown et al, 1997). In this study, the joystick was found to be more suitable for navigation tasks than the keyboard and mouse. The touch-screen and mouse were assessed for interaction tasks but neither of these devices rated best, although the touch-screen was found difficult to calibrate. From this research, it is clear that there is a need for further investigation into virtual environment access for people with learning difficulties.

2. INPUT DEVICE EVALUATION

2.1 Aims

- to evaluate the usability of the joystick for navigation tasks and the mouse for interaction tasks within virtual environments, for people with learning difficulties
- to obtain any usability guidelines for future virtual environment input device development

2.2 User Group

A user group was selected from the pupils who attend the Shepherd School in Nottingham. The user group attributes were as follows: size of group - 14; gender - 7 female and 7 male; age range - 8 to 19; cognitive ability - 2 moderate/severe and 12 severe learning difficulties; physical ability - co-ordination, gross-motor and fine-motor difficulties. 6 students had previous experience with virtual environments, 6 had used the joystick and 5 had used the mouse before.

2.3 Environment

The evaluations took place at the Shepherd School, in the 'Cyber Café' room. For some of the evaluations, the room was quiet and mostly free from distraction. During the majority of the evaluations, other students would come and go from the room, but would not attempt to disturb the subject.

2.4 Equipment

A colour computer monitor was used to display the virtual environments and a standard 2-button mouse was used for interaction tasks. 10 students used the Axys joystick (Suncom Technologies) and 4 students used the Wingman joystick (Logitech) for navigation tasks. The stick on the Wingman joystick is much taller and wider than the Axys joystick and is shaped to fit the hand.

2.5 Task

Each student was asked to complete navigation and interaction tasks, using the joystick and mouse respectively, within a virtual factory, café or supermarket. A demonstration of the devices and tasks was given before commencing the evaluations.

2.6 Assessment Measures

- Misuse of device: non-task related movement, harshness, pressing the wrong buttons, any other points
- Support required: spoken instruction, physical assistance, any other points
- Physical ability: sufficient strength, able to grip properly, any other points
- Workplace: able to reach, any other points
- Attention: on task, on device, on other
- User comments/reactions: positive, negative

2.7 Results

When performing navigation tasks with the joystick, 7 students showed controlled use of this device and 6 appeared to be holding the stick comfortably. The difficulties, which some of the students experienced with the joystick are listed in Table 1. The main usability problems experienced with the joystick were found to be: random movement; left/right movement causing too much rotation in the virtual environment; trying to use the device for interaction tasks and difficulties in gripping the joystick.

For interaction tasks, 6 students used the mouse quite well, with 7 gripping the device properly. Some students rested their hand on top of the device when using it, instead of gripping around the sides. As was found with the joystick, random movement of the device occurred and 3 students repeatedly pressed the mouse button, rather than just pressing it once and releasing it. One student required the evaluator to hold the mouse still, so that he could press the button and interact with the virtual environment. These, and further usability difficulties, which were observed are listed in Table 1.

Details obtained from the other assessment measures, i.e. support required, which were considered to effect the usability of the system are also listed in Table 1. Additionally, this table lists some suggested design guidelines for future virtual environment input device development, which have also been summarised in Table 2. Examples of these design guidelines are:

- Clear, understandable operation
- Consider the physical abilities of the user group
- Ergonomic design

These requirements highlight the importance of considering the cognitive and physical attributes of the user group when designing a product to meet their needs. In user-centred design, product developments are driven from user requirements, rather than from technological capabilities (USERfit, 1996). Therefore, it was decided that a user-centred design methodology should be employed, in order to design, develop and evaluate a virtual environment interface for people with learning difficulties.

Table 1. *Usability factors identified in the Input Device Evaluation and suggested design guidelines for future virtual environment system development (in italics).*

Navigation	**Further assessment measures**
Random movement of device, disorientation - *Clear, understandable operation* Too much left/right rotation, spinning - *Device more resistive to movement (may help to prevent some disorientation)* Trying to use for interaction tasks - *Functional clarity for achieving navigation and interaction tasks* Button misuse - *Not easy to press buttons by mistake* Base held still by evaluator - *Ensure that base of device remains stationary during operation* Physical help with some tasks, alignment guidance - *Able to use the device independently* Used two hands, tight grip - *Ergonomic design of device* **Interaction** Random movement of device - *Clear, understandable operation* Frequent pressing of buttons, pressing wrong button - *Not easy to press buttons by mistake* - *Only possible to press buttons which are required* Physical help with some tasks, held still to press button - *Able to use the device independently* - *Consider physical abilities of the user group* Not gripping around the sides of the device - *Ergonomic design of the device*	Prompting as to which device to use for a task - *Functional clarity for achieving navigation and interaction tasks* - *Only have one input device for navigation and interaction tasks* Encouragement, some distraction/distracted - *The device gives rewarding feedback* - *The device is motivating to use* Weak grip, shaky hand/arm - *Consider physical abilities of the user group* Desk too high - *Adjustable workstation* In Major Buggy - *Consider accessibility to the workstation* Fidgets in seat - *Workstation helps to engage the user* - *Integrated workstation* Some distraction/distracted - *Develop interesting, motivating and age appropriate virtual environments* Attention on devices when using them - *Device doesn't distract attention for the VE* - *Device is transparent* Attention on devices when switching between them - *Only have one input device for navigation and interaction tasks* - *The user does not have to keep locating a device* Frustration with tasks - *Ensure virtual environments are age appropriate*

Table 2. *Summary of the suggested design guidelines for future virtual environment system development*

- Clear, understandable operation of the device
- Functional clarity for achieving navigation and interaction tasks with the device
- The device is more resistive to movement (may help to prevent some disorientation)
- Only have one input device for navigation and interaction tasks
- Not easy to press buttons by mistake
- Only possible to press buttons which are required
- The device can be used independently
- Ensure that base of device remains stationary during operation
- Ergonomic design of device
- Consider the physical abilities of the user group
- The device gives rewarding feedback
- The device is motivating to use
- The device is transparent, i.e. doesn't distract attention from the virtual environment
- Adjustable and accessible workstation
- Workstation helps to engage the user
- Develop interesting, motivating and age appropriate virtual environments

3. USER-CENTRED DESIGN

3.1 Introduction

Central to this design process is usability, a crucial factor in the production of a successful human-computer interface. The usability of a product is defined in ISO 9241, part 11 (the British Standard giving guidance on usability) as 'the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use'. According to the ISO 13407 standard (human centred design processes for interactive systems) the key activities in user-centred design are:

- understand and specify the context of use
- specify the user and organisational requirements
- produce design and prototypes
- carry out a user-based assessment

In user-centred design, an iterative design process is employed, with the cycle of activities being repeated until the usability objectives have been attained (Daly-Jones et al, 1999).

3.2 Understand and Specify the Context of Use

This activity can be achieved by conducting a Usability Context Analysis (UCA), which involves the following research:

- User analysis: the product should be designed with reference to the characteristics of the end-users. Important factors to identify include the physical, cognitive and perceptual abilities of the user group.
- Task analysis: this should be carried out to identify the major productive goals, which a user can achieve, using the product.
- Environment analysis: it is important to understand the environment in which the product will be used, and how that environment should be constructed, so as to facilitate rather than impede the use of the technology (USERfit, 1996). This study involves an analysis of the organisational, technical and physical factors of the environment in which the product will be used.

3.3 UCA – Virtual Environment Input Device for People with Learning Difficulties

The UCA guidelines, available from Serco Usability Services, were utilised for this research. These guidelines include a 'context questionnaire', which covers the user, task and environment analysis. Initially, a 'Usability Team' was formed to advise and monitor the project development. This multi-disciplinary team included: project advisors; the design engineer; human-computer interaction and special needs experts; a usability specialist and an occupational therapist. To date, the User Analysis stage of the UCA has been completed and is described in the following section.

4. USER ANALYSIS

4.1 User Group

A user group of 21 students was selected from pupils who attend the Shepherd School in Nottingham. 14 of these students had previously participated in the Input Device Evaluation (see section 2). Students were selected who seemed to enjoy using computers and showed an understanding of how to use the virtual environments. The students ranged from age 7 to 19, with 5 primary, 8 secondary and 8 from the 16+ department of the school (9 of the students were female and 12 were male).

4.2 Skills and Knowledge

Details of the students' experience, with input devices, virtual environments and computers in general, was obtained through the Input Device Evaluation (see section 2) and the students' annual monitoring forms:

- Input devices: some of the students could use the joystick, mouse, trackball and keyboard and the majority of the user group could use a touch-screen and switch.
- Virtual environments: 6 students had previous experience.
- Computers: 4 students can switch on the computer and load a program and most of the students are motivated when working on a computer.

4.3 Cognitive Abilities

In order to gain some understanding of the cognitive abilities of the user group, two established assessment tests were used:

- The BPVS-II (British Picture Vocabulary Scale): a test of receptive English vocabulary, which correlates highly with verbal intelligence.
- The MAT-SF (Matrices Analogies Test – Short Form): a test of non-verbal reasoning.

4.3.1 Results. From the BPVS-II, 19 of the user group achieved in the extremely low score range for receptive English vocabulary, with two of the students scoring slightly higher and bordering the extremely low to moderately low score range (female aged 8:04, male aged 16:11). From the MAT-SF, 18 of the students achieved in the extremely low score range for non-verbal reasoning. In this case, 2 students scored in the low score range (female aged 8:06, male aged 8:06) and 1 student achieved an average score for his age (male aged 7:05). These measures are indicative of the students' cognitive abilities and in have shown that the students in the user group are generally in the moderate/severe level of cognitive functioning.

4.4 Physical Abilities

Details of the gross and fine motor abilities of the user group were obtained through the QNST-II (Quick Neurological Screening Test) and the students' annual monitoring forms. The tasks on the QNST-II provide an opportunity to observe the students' skill in controlling gross and fine muscle movements and their motor planning and sequencing abilities.

4.4.1 Fine-Motor Ability. 11 students were observed to have a good pen grip when writing and drawing and 15 showed good finger dexterity. A clumsy pen grip was noted in 10 students, with 1 student displaying hand tremor, which enhanced her difficulty in writing and drawing. Further fine-motor difficulties, which were observed, are listed in Table 3.

4.4.2 Gross-Motor Ability. Most of the user group members are independently mobile and over half showed good upper extremity movement and ability to reach. 3 of the students walk with an unsteady gate and 1 is normally in a special chair or using a walker. Co-ordination, motor planning and balance difficulties were observed in the majority of the students. Further gross-motor difficulties, which were observed, are listed in Table 3.

4.5 Perceptual Abilities

Details of the perceptual abilities of the user group were also obtained through the QNST-II, with further input from the students' educational files:

- Visual perception: all members of the user group have normal vision, though 7 are required to wear glasses to achieve this.
- Auditory perception: most of the students have normal hearing, though 6 have a history of ear infection or hearing difficulties.
- Visual-motor perception difficulties: there were many difficulties observed during the QNST-II, which can be categorised under this heading. The main difficulties experienced were with spatial awareness, ordering and sequencing, mixed laterality and bilateral tasks.

4.6 Further User Attributes

4.6.1 Communication. All members of the user group use Makaton signing, in order to communicate with other students and their teachers. There is a wide range of communicative ability within the group. A few of the students have good verbal communication, whereas others are limited to signs, gestures and some vocalising.

4.6.2 Behaviour and motivations. Almost half of the students displayed distractibility and a few showed a lack of self-confidence. The virtual environment system should aim to gain the full attention of its user and to build his or her confidence. A list of activities, which the students enjoy, was also obtained, e.g. music, art, sport and writing.

Table 3. *The physical attributes of the user group*

Fine-Motor Ability	Gross-Motor Ability
Good fine-motor ability - Good pen grip: 11 - Can isolate finger press: 15 Fine-motor difficulties - Clumsy pen grip: 10 - Motor planning difficulties: 19 - Motor tension: 4 - Slight hand tremor: 1 - Limited wrist movement: 6 - Wrist dip (muscle hypertension): 6 - Weak grip: 1 - Finger dexterity difficulties: 6	Good gross-motor ability - Independently mobile: 20 - Good upper extremity movement: 11 - Good reach ability: 15 Gross-motor difficulties - Unsteady gate: 3 - Uses a walker: 1 - Unsteady arm movement: 2 - Rigid arm: 1 - Difficult to fully stretch right arm: 1 - Co-ordination: 14 - Motor planning: 18 - Balance: 16

5. CONTINUED RESEARCH

Following the completion of the UCA, the user requirements for the input device will be identified. These will then be translated to design objectives to produce a 'product design specification'. The suggested design guidelines, identified from the Input Device Evaluation (see section 2) will also be incorporated into the design specification. A review of existing computer interface technology, including assistive computer access methods and virtual reality interfaces, will be conducted to identify any existing devices, which with adaptation could provide a potential solution and to identify technological opportunities for satisfying the design requirements in novel ways. The design specification will be used to guide both concept and prototype design, by checking the developing input device(s) against the design objectives, and established techniques for concept and prototype development will be employed. Storyboards of the concepts will be reviewed by the Usability Team, in order to modify the design before commencing to the prototyping stage.

In a usability evaluation, the User Group will test the prototype(s) with appropriate virtual environments. The results from this user based assessment will be continually fed into concept design, until the design objectives, outlined in the design specification, have been attained, see Fig. 1. The completion of this study should result in the production of a virtual environment input device for people with learning difficulties, which satisfies ISO 9241 (the British Standard giving guidance on usability).

Acknowledgements: The authors would like to thank the Shepherd School for their co-operation with this research.

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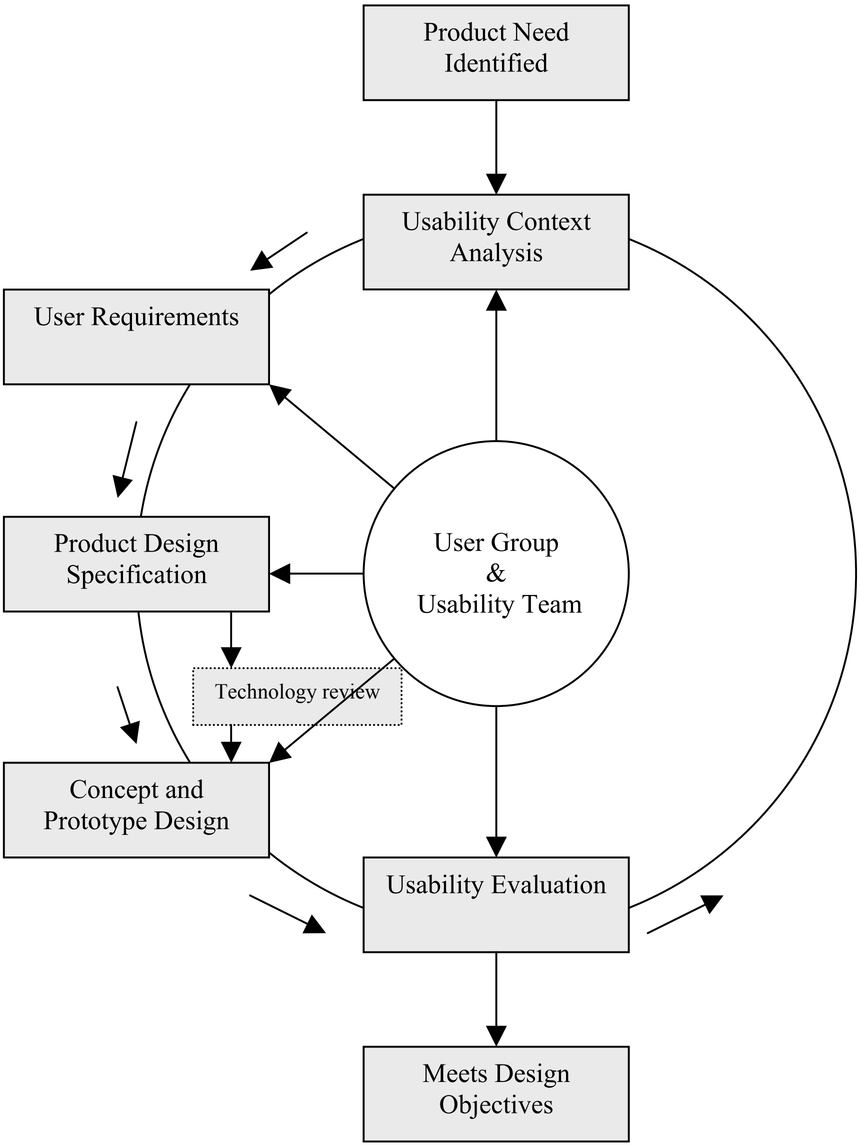

Figure 1. *The user-centred design cycle*

Collaborative networked framework for the rehabilitation of children with Down's Syndrome

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ABSTRACT

This paper describes a reference architecture to support a multi-user virtual communication platform that enables rehabilitation and social integration of Down's Syndrome children. The platform, based on an on-line virtual collaborative environment supported by the World Wide Web, includes collaboration and interpersonal communication devices and data collection mechanisms to provide management information for system and effectiveness evaluation. It allows children with Down's Syndrome, geographically spread in schools and homes, to access a distributed virtual platform able to offer communication and shared construction processes. This will leverage the exploitation and development of communication and socialisation abilities, creating conditions to the exploitation of new rehabilitation patterns.

1. IS VIRTUAL EFFECTIVE?

Virtual derives from the Latin *virtus*, which means strength and power. In fact, it has little relationship with false or illusory. As Pierre Levy states, "the virtual is by no means the opposite of the real. On the contrary, it is a fecund and powerful mode of being that expands the process of creation, opens up the future, injects a core of meaning beneath the platitude of immediate physical presence" (Levy, 1998).

In fact, virtualisation is mostly a process of actualisation and effectiveness, a dynamic operation of transformation and creation of solutions. It is not imaginary as it produces effects (Levy, 1998). Consequently, the expression Virtual Reality seams a paradox as the virtual allows real cognitive representation and experimentation (Cadoz, 1996). Indeed, virtual tools allow objects, entities and processes representation in a universal and integral unique way: not also they are an extension of human representation, cognition and recognition, but also they extend human interaction and social abilities through a ubiquitous and interactive mean. In this context, virtual solutions are a powerful mechanism of knowledge transposition to "real world" scenarios in a dual process where, on one hand, "real word" information affects virtual interaction and, on the other hand, virtual interactions modify "real world" scenarios.

Moreover, under the context of networked virtual scenarios, there is a dynamic experience of a collective context, a virtual world of significations, which is shared by the participants and reinterpreted by them, a projection of presence in a shared environment (Levy, 1998) where contexts are not imposed but instead result from the activity of the participants.

The collaborative framework presented aims to allow the construction of a virtual shared space, a context of meaning and knowledge where usually excluded and geographically dispersed individuals can communicate, participate and learn through the transposition and change of information from real and virtual words.

2. REAL PROBLEMS, VIRTUAL EFFECTIVE SOLUTIONS

Under the context of disability, spatial dispersion scenarios are very frequent. Not only due to social exclusion but, currently and under the Portuguese special educational policies, due to the processes of integration in regular schools instead of in dedicated and geographically concentrated centres. Indeed, this new scenario creates a new gap as, nowadays, disabled children, integrated in regular schools, spend most of the time of their school days in activities that do not promote collaboration and real participatory processes toward their daily social inclusion and the rehabilitation of transversal problems. Consequently, and in order to assure communication, participation, learning and rehabilitation processes, we propose a technological tool

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that will enable and promote the virtualisation of those processes between a network of individuals, specifically children with Down's Syndrome.

This tool will provide to its users the participation in a shared, situated space as a social interface platform of mediation and communication. Underling the importance of a constant interaction between the individuals and contexts (ICIDH-2, 1999), this platform is expected to create the appropriate conditions, so that individuals can build their own learning environment and collaborate in their own rehabilitation processes in a participated and autonomous way.

2.1 General Characterisation of the Down's Syndrome

Down's Syndrome or 21 Trissomy (due to an extra copy of chromosome 21) is the most frequent genetic cause of mental retardation and affects up to 1 in 700 live births (Reeves, 2000). Individuals with Down's Syndrome, besides mental retardation, also exhibit congenital heart disease, development abnormalities and other health problems.

As far as cognitive disorders are concerned, these individuals have linguistic incapacity because their strongest deficit is in the language area. Furthermore, limited language skills intensify the already present difficulties in the symbolic and social areas. Nevertheless, Sigman (1999) states that children with Down's Syndrome, when compared with other mental retarded groups, are socially communicative and capable of imaginary play (Sigman *et al*, 1999). The main reasons for this language deficit are, first a hearing deficit, and second, a deficit in simultaneous and sequential cognitive processes, specifically with chronological understanding, successive event synthesis, sequential hearing memory and recent acquired knowledge construction (Condeço *et al*, 1999).

Besides this, Down's Syndrome children prefer to learn by themselves through experience and without a close adult mediation as they benefit from distal communication processes and not from proximal ones. Proximal communication processes are human related and without many mediation objects, while distal ones are mediated by tools and artefacts (Condeço *et al*, 1999). This fact seems to be related to a typical Down's Syndrome phenomenon of social avoidance in learning activities.

Therefore, the fact that Down's Syndrome children have good visual performances, that they prefer distal communication processes, that they are social and communicative and that they have a great empathy with computational applications, reinforced our belief that a multi-user virtual environment could be helpful in their rehabilitation. Moreover, the proposed framework, because it is a networked environment, benefits from the World Wide Web collaborative potentialities namely concerning: targeting people that are geographically dispersed; easing the customisation and update of curricula; enabling shared construction processes (network supported collaborative work).

2.2 Theoretical Approach to the Virtual Environment

The theoretical approach to this framework follows constructivist and pos-constructivist theories form Piaget and Vygotsky as it emphasises the importance of social development, dialogue and interrelation in knowledge construction and in educational processes (Tryphon, Vonèche, 1996). Therefore, the virtual environment proposed aims to stimulate cognitive construction processes in open learning environments on a profoundly heuristic basis.

Also, it is believed that learning phenomena are situated processes as human cognition and learning are embedded in specific contexts and are constituted through processes of interdependence, socially and ecologically grounded and mediated by tools and artefacts (Littleton, Häkkinen 1999). Therefore, this framework also follows Clancey (1997) situated cognition theories, which state that cognitive processes are contextually situated. The model is, then, based on interactive role-playing schemes allowing children to participate in the activities through the manipulation of characters (avatars), scenarios and objects and the consequent shared construction of the learning environments.

The exploitation of these narrative and role-playing schemes is deeply studied by Schank (1998). This author states that intelligence depends upon the ability to translate descriptions of new events into labels that help in the retrieval of prior event in a process of constant narrative construction. Under this context, role-play and shared narrative construction improve not only knowledge consolidation and generalisation but also participatory and integration processes.

It is well known that fantasy and imagination have a great importance in childhood development. To imagine, build and shape something in a virtual environment is to experiment a solution for a real problem with a minor risk of failure or frustration; furthermore, it is also of most importance to social and emotional development, and also to improve linguistic skills, as it involves representation processes.

Moreover, shared distributed narrative environments are of most importance to isolated children because they can help to overcome the absence of a co-temporal and co-spatial playmate, enabling storytelling processes to play their triple role, even for children in different locations: cognitive (favour human memory and experience), social (favour a social construction of the self) and emotional (exteriorisation of experiences).

This collective narrative construction model is also based on the presumption that incapacity is, rather than just a dysfunctional cognitive phenomenon, a multi-dimensional issue comprehending educational, social, and behavioural aspects. Moreover, the social avoidance phenomena, the preference for distal communication processes the typical sequential cognitive difficulties of children with Down's Syndrome lead the authors to propose this narrative construction model.

3. THE MODEL

The conceptual supportive model of this framework is materialised on a networked communication system (figure 1) and aims to enable participation and integration processes of geographically and socially isolated children. According to Schroeder's virtual reality categorisation (Schroeder, 1997), this model is both "immersive" and "second person" as it allows, besides presence virtualisation, individuals representation by avatars that allow peer interaction as well as contexts manipulation and narrative construction.

In the model, the different individuals share a collaborative environment which interface is a graphical scenario. To interact and participate, children dispose of other scenarios as well as of characters and objects that they can select and manipulate to create their own environments autonomously and that are organised in personal and collective archives allowing shared and open collaborations as well as one-to-one.

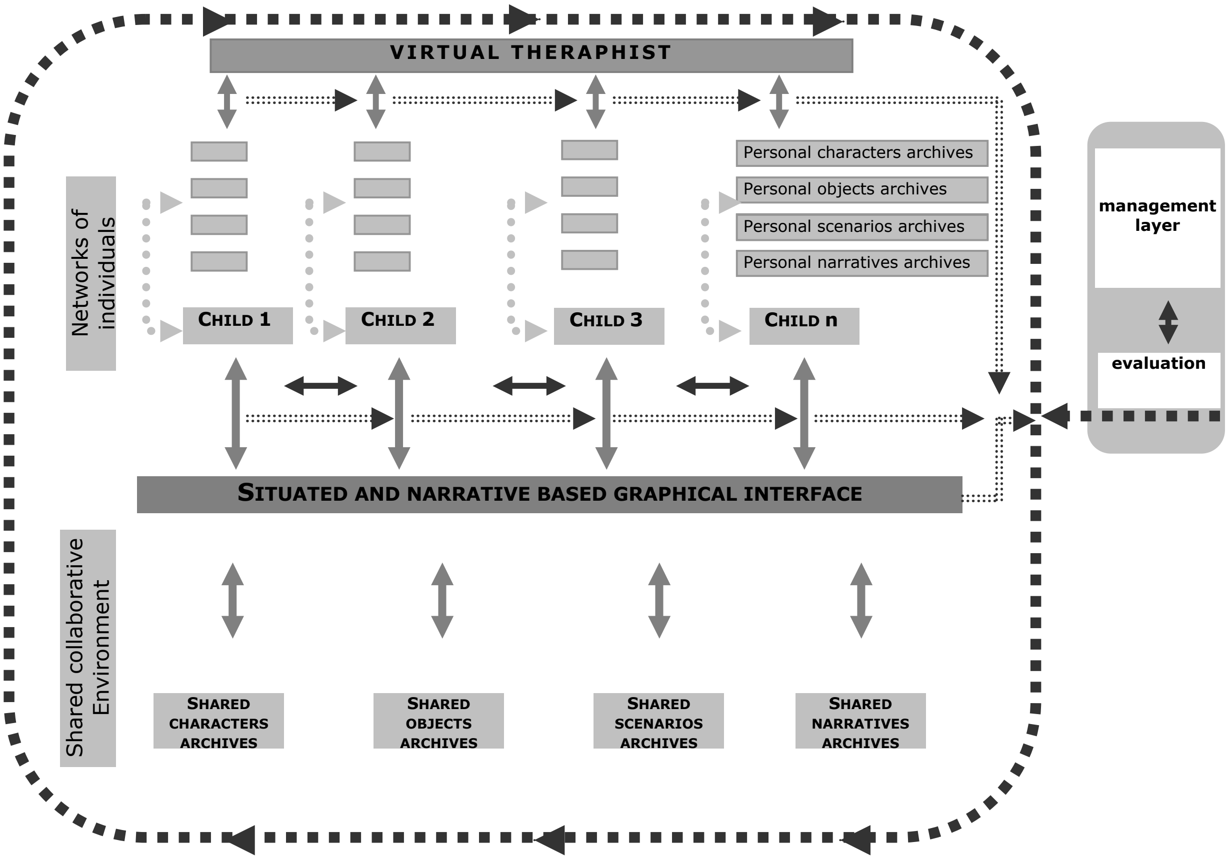

Figure 1. *Conceptual model.*

The conceptual model also comprises the possibility of intervention of a virtual therapist to mediate communications and to launch activities, which take place above this muti-modular and shared environments build by the children, favouring processes of situated learning and natural knowledge construction. Moreover, it also proposed the inclusion of a management and evaluation layer, enabling system feedback and analysis, therapeutic intervention and system management functions (configuration, updating, accounting, etc.).

3.1 Main Facilities and Characteristics

The proposed framework favours not only the collaborative construction of narratives and visual scenarios but, also, of the learning environments in which the curricular activities take place. Nevertheless, besides curricular activities, other activities towards real system immersion and effectiveness of cognitive processes virtualisation are also proposed. Four levels of activities can be distinguished: activities promoting system interaction; activities inducing peer interaction; curricular activities; activities stimulating the construction of situated knowledge (figure 2).

Activities promoting system interaction are related with initial interaction processes in which children will be able to work on simple play tasks towards system motivation.

Activities inducing peer interaction aim the learning of socialisation abilities, namely the training of simple socialisation acts like salutations, farewells and requests by the use of games and individuals presentations.

As far as the curricular activities are concerned, relevance will be given to the learning of specific curricular areas, mainly related with semantics and pragmatics (Nadel (ed.) 1988), (Kumin, 1994). Specifically and according to Nadel and Kuman studies, we pretend to work on the following abilities: categorisation, classification and sequencing; numerical; reading; hearing discrimination. Transversally to these abilities we also propose general task schemes towards cognitive stimulation such as repetition, contrast, manipulation, generalisation and reinforcement.

The fourth level of activities (stimulating the construction of situated knowledge) is the layer of contextualisation and systematisation of the former three. It is in this last level that the dynamical holistic model is materialised in a dialectic process between the curricular activities and the social interaction contexts. This level of situated learning will assure knowledge generalisation through different contexts and, consequently, abstraction and knowledge consolidation as it allows the creation of social interaction environments in a process that privileges operative learning from natural and situated actions (Nadel (ed.) 1988).

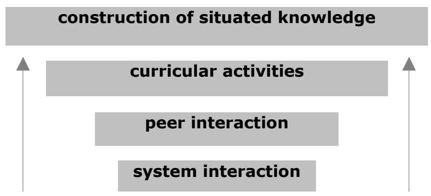

Figure 2. *Activity levels.*

The typical processes that assure this last level are exactly story-telling and role-playing schemes. For example: the curricular activity that works numerical and sequencing abilities would be situated in the environment garden or supermarket in which children would have to discriminate, select, and count objects (flowers or groceries).

In order to assure the above mentioned processes, narratives must be parameterised in order to establish patterns for used scenarios and objects in thematic groups (modules) in order to automatically or manually launch each module when a theme is invoked. Also, given opening scenarios should invoke and invite communication processes. Both the given and the shared constructed modules should be archived in order to create a relational database containing the updated versions of the available data (figure 3).

Finally, the different local and shared archives allow the creation and interrelations of scenarios, objects and characters contributing to the shared construction of the learning environment (figure 4).

3.2 Implementation Strategy

The implementation of a network virtual environment that allows multiple geographically dispersed users to interact in real time with a deep sense of realism and an immersive experience is a complex task that must be correctly assured in order to guarantee system effectiveness. As Singhal (1999) states, a network virtual environment should offer both a shared sense of space, presence and time and a way to communicate and share.

Generally, the main dimensions to consider in the implementation process are bandwidth (distributed virtual reality systems require enormous bandwidth to support multiple users, and the exchange of graphics in real time), distribution (multicast, unicast or broadcast), latency (which influences the interactive and dynamic behaviour of the environment) and, finally, reliability which forces a compromise between the former three dimensions, assuring that data sent is always received correctly (Macedonia, Zyda, 1997).

Although we agree that the correct analysis of the above mentioned dimensions is crucial to system effectiveness, throughout this research, we are specifically concentrated on investigating data distribution and peer communication mechanisms. According to Macedonia and Zylda (1997), data can be distribute in four different ways: replicated homogeneous world database (every participating system must be initialised with the same and unique database), shared centralised databases (only one user at a time can modify the database), shared distributed databases with peer-to-peer updates (shared memory architecture dynamically updated and multicast based) and, finally, shared distributed client server databases (partitioned among users and mediated by a central server).

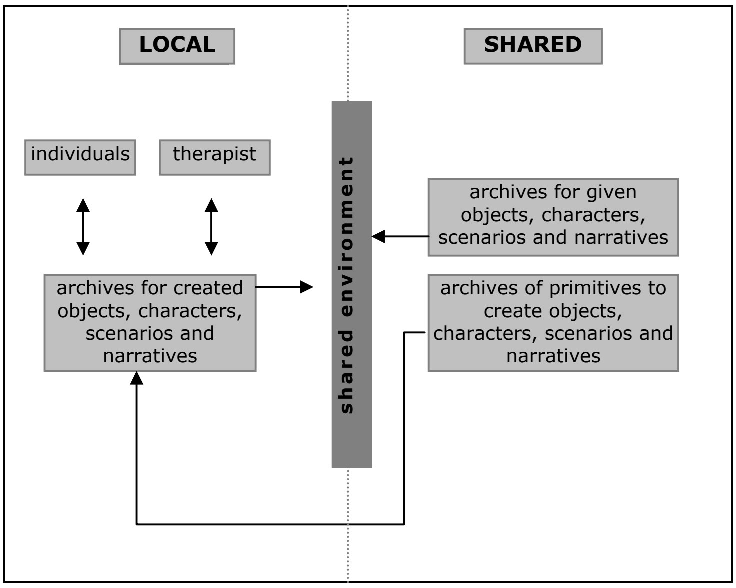

Figure 3. *Example of the interrelations among the modules.*

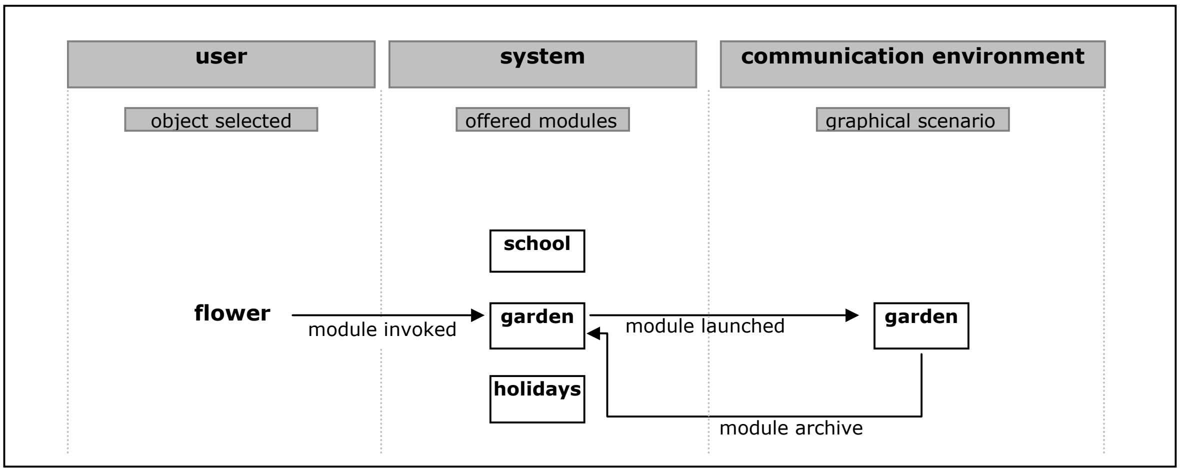

Figure 4. *Local and shared archives.*

As the aim of this project is to conceive a technologically flexible architecture, the solution chosen must be compatible with the conceptual characteristics of the presented collaborative environment as it will influence and support global communication and visualisation aspects. Under this context, special attention will be given to social and communicational requirements and collaborative activity requirements. Globally, this discussion should also consider the need to implement virtual environments capable to emulate real participation scenarios, especially concerning: graphical representations of real world metaphors, spatial representation, manipulation and navigation possibilities, multi-dimensional representation, dynamism and realism.

Considering the evaluation layer, and in order to provide the necessary and organised information to system adaptation and optimisation and to support immediate monitoring and intervention, the authors also aim to implement data collection, parameterisation and visualisation mechanisms.

3. FUTURE WORK

The collaborative networked framework proposed, as an open and shared communication environment, points to a new approach to distance learning and rehabilitation interventions. It explores the potentialities of virtual environments while powerful tools for real multi-modal interaction and shared knowledge construction.

The authors, of course, believe that the main challenge is to capture the complexity of human learning processes in a systematic manner and to express them metaphorically in real platforms of effective interaction and communication.

In the future, and besides a continuous work toward the research area of technological platforms for people with special needs, the authors aim to consolidate and develop research activities on methodologies and technologies for other networked collaborative environments, specifically to global distance learning systems.

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Special considerations for navigation and interaction in virtual environments for people with brain injury

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ABSTRACT

When a Virtual Environment (VE) is designed, decisions regarding the navigation of the viewpoint, interaction with objects, and the behaviour of the VE itself are made. Each of these can affect the usability and the cognitive load on the user. A VE that had previously been constructed as a prototype tool for the assessment of brain injury has been studied to establish the consequences of such design decisions. Six people, two with brain injury, have used the VE to perform a specific task (brewing coffee) a total of ten times over two sessions separated by a week. These trials were video recorded and analysed. Results and implications are presented and discussed.

1. INTRODUCTION

The use of Virtual Environments (VE) for cognitive rehabilitation is an active area of research and is typified by co-operation between research institutions, hospitals and rehabilitation centres (Riva *et al*, 1999). Application areas are diverse including phobia treatment (for example, Weiderhold and Weiderhold, 1999), treatment of post-traumatic stress disorder (Hodges *et al*, 1999), cognitive assessment (and rehabilitation) (Riva *et al*, 1999), training of people in daily living tasks (Brown *et al*, 1999) and many others. However, the majority of these address the issue of whether a VE can be used for a particular application, and infer from this that the system itself, consisting of hardware and software, is thus adequate.

Virtual Environments supposedly allow people to be within an artificial environment as if in reality. This is achieved through a combination of special hardware for capturing human movements, speedy computer calculations and hardware for displaying the result to human senses. Much philosophical and physiological work has been performed in the area of increasing the level of presence – the feeling of being in a VE, though an in-depth discussion of this is beyond the scope of this paper. However, the experience of a VE as yet is far from being mistaken for reality. One of the biggest hurdles is the devices that a person is required to use for imposing their will on the system and for perceiving the result thereof.

When a VE is designed, decisions are made as to the hardware platform, software and peripherals, as well as the actual content and functionality of the VE itself. Each of these can have a dramatic effect on the usability. In the area of cognitive rehabilitation, it is essential that a VE tool is not rendered unusable due to early design decisions, particularly as people with a cognitive disability may be less tolerant to a poor interface.

To this end, we have investigated the effects of the design decisions on a VE built for a PC desktop VR system, originally as a prototype for cognitive assessment. This paper details the construction of the VE including guiding principles used and assumptions made, describes the studies performed, the observations made, and the implications of the original decisions.

2. PROJECT DESCRIPTION

The Department of Rehabilitation at Lund University Hospital and the Department of Ergonomics at Lund University are presently co-operating in a long-term project with the following goals:

- to determine whether a VE tool can be a useful complement for the rehabilitation of people with an acquired brain injury and an effective tool in everyday life;
- to find the optimal interface between a VE and the user (and to determine which groups of people with brain injury would be able to use a VE);
- to investigate transfer of training of practical tasks learnt using a VE to the real world; and
- to develop at least three practical applications of VE for rehabilitation.

Each department brings its own unique areas of competence to the project; the Department of Ergonomics is specialised in human computer interaction, and the development of VEs for various applications, whilst the Department of Rehabilitation has expertise in the practical and theoretical aspects of rehabilitation of people with brain injury. The latter was also the first clinic in Europe to be acknowledged by the Committee for Accreditation of Rehabilitation Facilities (CARF).

2.1 The user group

A large group of people who suffer a brain injury are able to retrain their daily living skills and again participate in society. This group is not homogeneous and includes those who have suffered a brain injury through either illness or trauma. Furthermore, cognitive difficulties can be both diverse and obscure. The VE based rehabilitation tools are therefore aimed at this group as it is hoped they can most benefit. In order to reduce complexity, is initially assumed that the people are able to physically manage ordinary computer equipment such as buttons, touch-screen, mouse and joystick, though we do not assume dexterity in both hands.

2.2 Previous work

To date, we have looked at the potential of using a VE for brain injury rehabilitation through testing and interviews with occupational therapists (Davies *et al*, 1999). A simple environment was built based on a well documented, standard, real world assessment of cognitive function used currently by occupational therapists – the task of brewing coffee. The results and comments indicated that the tool has potential as a complement to existing methods of assessment and training, particularly at an early stage when the patient is physically unable to perform the task in reality, in situations where it isn't practical to train repetitively in reality, and for people who may be more interested in computers than brewing coffee. Many suggestions were also made as to other applications of VE technology to brain injury rehabilitation. It was concluded beneficial, therefore, to continue and to delve deeper into what happens at the interface between the user and the computer when sharing a VE.

3. HUMAN – VE INTERACTION

There are many aspects to the human-VE interaction problem, such as:

- physical loading problems associated with wearing often heavy devices or holding limbs in uncomfortable positions for a long period (Nichols, 1999);
- physiological effects such as nausea and eye discomfort when using a HMD (Cobb *et al*, 1999);
- method of interaction with the VE; and
- extraneous cognitive load – that is the load on the user above and beyond that of performing the task which can be attributed to the usage of the tool itself.

The first of these can be mostly side-stepped by using desktop VR with standard input devices, though this may increase the cognitive load due to a lesser degree of immersive feeling. The last two are the basis for our further study.

Cognitive load is an all-pervasive factor, which must be considered at all stages of VE design and usage. A general rule-of-thumb is that too much extraneous cognitive load will distract from the concentration on the task (as[one must instead concentrate on just interacting with the VE). People who have cognitive disabilities may be especially sensitive to this, so it is important to try to reduce this effect as much as possible.

The method of interaction can be further broken into navigation of oneself in the VE, and interaction with objects in the VE.

3.1 Navigation of oneself in the VE

Navigation in a VE can have two meanings; finding one's way in a large environment; or manipulating the viewpoint (as seen through the computer screen) to see what one wishes to. The latter is most directly connected to the input devices and is of interest to this study, though the former does also have an effect, particularly for people who find it difficult to remember parts of the VE not currently in view.

The form of navigation can range from completely automatic to self-controlled, with various forms of 'half-automatic' in between. Navigation can be either from a first person view – you see on the screen what you would see from your own eyes in the VE; or third person view – you control an avatar which you see perhaps from behind.

Automatic navigation implies that the computer tries to decide what the user wishes to look at depending on their intention. Their intention is inferred from their input and previous actions (and thus the state of the system). The user input is used to initiate events, hence navigation of the viewpoint comes as a side-effect of the initiation of events (of interaction). This form of navigation is expected to be least cognitively taxing on the users, since the only interaction with the computer is to initiate events, which is directly related to the performance of the task. If the user also has to position the viewpoint, this is an extra level of complexity that one normally doesn't have to worry about in reality (do you notice that you move from place to place when making coffee? (Perhaps if movement is difficult, for example in a wheelchair, but otherwise, probably not.)

Self-controlled navigation is performed through some input device such as a joystick, mouse or keyboard. The type of device and how it is programmed can affect the usability of the device, for example, Peterson *et al* (1998) have found that a joystick allows precise manoeuvring, but that a Virtual Motion Controller (a type of stand-on-platform joystick) is better for route learning. It is usual to limit the number of degrees of freedom to that required by the application. There are two basic flavours of self-controlled navigation; walk through and fly through. In the former case, the height is fixed and two degrees of freedom are permitted; movement forwards, backwards and turning to the left or right. Sometimes an extra degree of freedom is added to allow sideways movement. One can also normally walk up and down stairs, and perhaps jump onto low objects. Turning can be as for a person, in that the view can be spun on a point without forward or back movement, or it can be as for a car in that one must also move forward or back to actually turn, and the turn is an arc.

Automatic navigation is best suited to situations where the entire VE can be viewed at once, whereas, some form of self-controlled navigation is required when the VE is large or has hidden areas.

In between these extremes, there is what may be dubbed *half-automatic navigation*. This is where the user has a level of control, but allows the computer to aid in an intelligent way. Half-automatic can use a variety of algorithms, for example, with the user still controlling navigation with an input device, the computer always moves the viewpoint towards and away from the last selected object (or perhaps the object over which the mouse pointer is currently resting).

Finally, there is a further complication of body versus head movement (coarse versus fine movement). Many 3D games use a combination of mouse movement for head positioning, for example, and keys or joystick for body positioning. However, this requires the user to be adept with several input devices at once.

3.2 Interaction with objects within the VE

Once the user has positioned the viewpoint, they may wish to actually do something (since there is a task to be performed). There are at least three things one can do with virtual objects (or indeed real objects):

1. *activate objects* in various ways such as turning on a switch, opening a packet of coffee, pushing a button or turning off a tap;
2. *move objects* from one place to another (and rotate if appropriate); and
3. use one object with another (*object-object interplay*), for example, using a knife to spread butter on bread, or using a coffee scoop to take coffee from a packet to put into a filter.

The user tells the computer to do one of these by giving a command through an input device. This in turn may initiate an event or cause a change in the state of the VE. There is a plethora of input devices such as: standard PC mouse, dataglove, gesture recognition, voice recognition, force feedback haptic device, touch screen and interaction with a real object to effect a change in the VE. Some of these double as display devices. Again, the input device itself affects the usability. Werkhoven and Groen (1998), for example, performed a study comparing object manipulation performance using a dataglove and a six degree of freedom spacemouse in an immersive VE. This showed that a dataglove wins in both accuracy and speed for such tasks. However, similar work has not been found with regard to desktop VE input devices.

4. A STUDY OF HUMAN – VE INTERACTION.

In the design of any VE, a number of sometimes arbitrary decisions must be made concerning the computer system, the input and output devices, the structure of the interaction and of the VE itself. These affect the usability of the VE. The aim of this study was to take a deeper look at the effects of the design decisions on the coffee making VE assessment tool. These are grouped into overall guiding principles which were used whenever a decision was to be made regarding the design, and general assumptions.

4.1 Guiding Principles

The guiding principles were primarily based on a wish to reduce the complexity of the interaction with the VE and thus reduce the extraneous cognitive load on the user. At a later stage, these may also be questioned.

1. Only things that can exist in the real environment should be in the virtual, for example, no extra buttons or icons such as found in ordinary interface designs. Similarly, objects should act as expected in the real environment. *Reason:* People are accustomed to the real world and tend to notice when objects in a VE differ from reality. Furthermore, keeping the VE 'pure' avoids the question of what extra features are required and the effect on the user, both in cognitive load and effect on transfer of training.
2. The user must have free choice in the initiation of events, being able to choose to do things in whatever order they wish – even the wrong order (this implies that the system must react in a sensible way in all situations, with regard to principle one). *Reason*: One way of learning is by trial and error. Similarly when the VE tool is to be used for assessment, it is the errors that give the most information. Therefore, all (or at least almost all) possible orders of task performance must be possible and error situations programmed in (e.g. water running out of the coffee machine if the pot is not returned).
3. Where a decision has to be made between two or more design alternatives, the simplest should be chosen. The definition of 'simplest' may vary from case to case but must always take into regard cognitive load for the user. *Reason*: We are striving for a low extraneous cognitive load. However, in many situations, it may not always be clear which choice will be better, therefore, careful documentation and evaluation is essential.

4.2 Assumptions

In the making of the coffee machine VE, the following assumptions were made:

4.2.1 Hardware and Software. A standard PC was used, not a high-end graphics machine. This was due mainly to cost and availability of such machinery in the hospital environment. Furthermore, modern graphics cards for 3D games are now capable of rendering at a more than adequate rate, and stereo sound cards are both common and cheap. The software used was Superscape VRT, and the VE included realistic sound effects.

Similarly, standard input and output devices were assumed, in this case, mouse, computer monitor and speakers (desktop VR). This was again due to cost, compatibility with ordinary computers and availability, but also since the effect of putting a head mounted display on somebody who has suffered a brain injury is as yet uncertain. Furthermore, people can learn well using desktop VR. (Brown *et al*, 1999). No device was required for movement of the viewpoint as this occurred automatically.

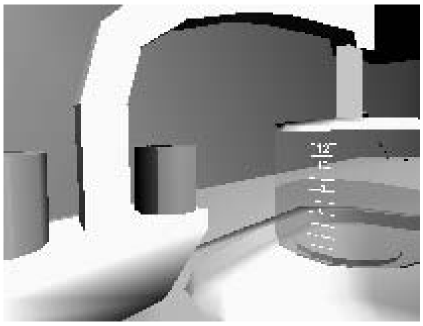
4.2.2 Navigation of the viewpoint. Navigation was completely automatic.
First person view was used to bring the user conceptually closer to the VE – it is themselves performing a task – thus perhaps avoiding an extra level of complexity. As a bonus, we also avoided the problem of a virtual body covering parts of the already cramped viewing area.

4.2.3 Interaction with virtual objects. All object interaction was by single mouse clicks (no drag-and-drop, double clicking or other complex movements were required).

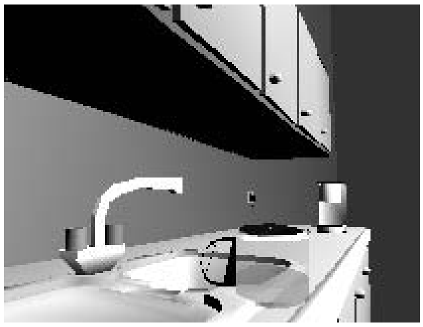
- Objects could be activated by single mouse clicks (requiring no turning, dragging or pulling actions).
- Objects could be moved by 'picking up' which placed them in the foreground (Fig. 1 c, e, f). This was performed by clicking on the object. Objects thus picked up were then carried (without a visible hand) with the viewpoint and could subsequently be put down by clicking where they were to be placed.
- An object could be acted upon by another object by using the object in the hand with the next object clicked upon (Fig. 1 e, f)

Objects which could be activated, picked up, put down or acted upon by another object didn't display any feedback before being clicked upon (such as mouse pointer alteration, sound cues or highlighting). This was due to principle 1 above.

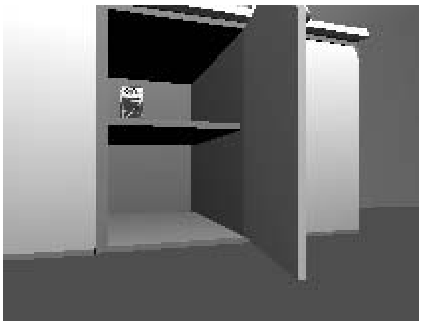
(a) Start View



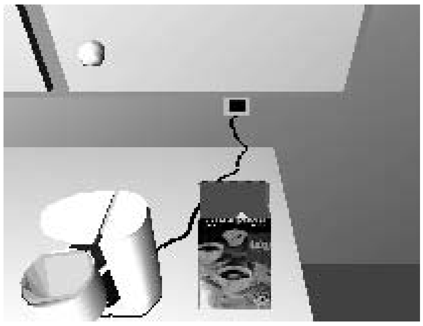
(b) Filling with water



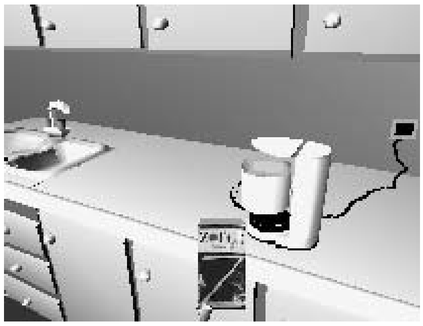
(c) Moving back to the machine



(d) Looking in a cupboard



(e) Putting in a coffee filter



(f) Putting in coffee

Figure 1. *Various stages in the coffee making process.*

5. METHOD

To establish the effect of the design decisions and assumptions on the usability of the coffee brewing VE, a series of case studies were performed in which six people were instructed to brew coffee using the VE tool. The subjects repeated the task a total of ten times over two sessions separated by a week to allow for an estimation of short and long term learning effects. Each subject used the VE singly and had no previous experience of it.

5.1 The Subjects

The subjects consisted of two patients with acquired brain injury (one man and one woman) and four hospital personnel (one man and three women), all with word-processing level computer experience, though not 3D game players. A couple had used a computer a little more in their daily work. The ages ranged from 35 to 58. All could make coffee in reality.

5.2 Experimental Set-up

To record material for analysis, two video cameras were used, one at the front of the subject to capture facial expressions, body movements and sound, and one from the side to capture the whole scene as well as input device usage. A video signal was also taken from the computer and mixed in with one of the other video signals.

At the start of the first session, each subject was shown a video that illustrated how to use the VE. They were then asked to 'brew coffee' using the VE, which they repeated five times. A week later, each subject came back and was again asked to brew coffee five times using the VE. This time, there was no instruction beforehand. At the end of the second session, an interview was conducted. This consisted of 14 questions to which the subjects could freely answer. Questions were aimed at establishing the subjects' own views of the tool, thoughts on the navigation and interaction methods and to highlight any particular problems experienced. A couple of questions were also aimed at determining the experience of the test process itself.

5.3 Analysis Methods

The analysis was performed from the videos, observations, and the interview. The coffee brewing task was broken logically into ten steps which are categorised according to object interaction method (Table 1).

From the videos, a detailed description of the actions, specific problems, comments, and other signs from the subject were made for each step. Times were gauged for the performance of each step, for each trial in

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each session for each subject. Total completion times were measured from the videos and an optimal time was computed for each step as the median value of each step from the six fastest total times. The optimal times were then used to normalise the data and to calculate the normalised median value for each step over all the subjects and tests. A tally was also made of the number of instances the time to perform a step was more than double the optimal time. Median values were used rather than averages to reduce the effect of large outliers. Comments from the interview were summarised.

Table 1. *Coffee brewing steps.*

Step	Task Description	Interaction Method
1	Take the coffee pot from the machine to the sink.	object movement
2	Fill the coffee pot with water.	object activation
3	Take the coffee pot to the machine, put the water in and close the lid.	object movement + object activation
4	Put the coffee pot on the hotplate in the machine.	object movement
5	Take the coffee filters from the cupboard and place one in the filter holder.	complex
6	Put away the filters.	object movement + object activation
7	Take the coffee from the cupboard and put scoops of coffee into the filter in the holder.	complex
8	Put away the coffee.	object movement + object activation
9	Close the filter holder.	object activation
10	Turn on the machine.	object activation

Note that viewpoint movement is not explicitly mentioned, as this is automatic. Steps 5 and 7 include several object interactions, though primarily object-object interplay.

6. RESULTS

6.1 Videos and interviews

Specific points of note from the analysis of the videos and the interview are summarised below.

Automatic Navigation, for the most part, seemed to present no major problems. However, some situations occurred where the view made it difficult to see clickable objects. A need for a means to change the view was apparent, mainly to take a step back. Five of the subjects tried to find something to click on to change the view and one expressed a need to get closer to objects. One subject mentioned that the view changing was considered a confirmation of being on the right track, though one of the patients found the automatic view changing to be confusing.

Object Activation was also managed without major problem. The main difficulty was in finding the sensitive area for clicking on, with some people clicking just beside objects to active, particularly if the current view made the object small. One subject expressed a need for quick feedback of correct object activation.

Moving Objects provided some problems, particularly in the start as the subjects tended to try to drag-and-drop the objects. This was even the case for one subject who expressed no knowledge of drag-and-drop. The sensitive areas tended to be missed again, and all of the subjects had trouble comprehending when objects were being held (though two assured that the concept was understood). The sensitive areas for the placement of the coffee pot on the coffee machine element or the sink were often missed.

Object-Object interplay posed one specific problem. When the coffee filter holder was open with a filter placed inside, and the packet of coffee was being carried, clicking on the filter holder took over a scope of coffee grounds to the filter. All but one of the subjects had difficulties figuring out how to tell the system when there was enough coffee and to close the filter holder.

The subjects showed a tendency to be disturbed by their own mental models, both in the expectation of how the coffee machine worked and in how the VE worked. One was used to another type of coffee machine and found it difficult to get used to this one. This person also insisted in replacing the coffee packet in an upper cupboard though every time it must be taken from a lower cupboard. Another subject insisted that all the cupboard doors must be closed to continue. Yet another subject wanted to try to remove the filter from the holder (it actually comes out automatically), lift the lid of the filter holder (rather than rotate out the filter holder) and turn on the water to initiate the action of moving the coffee pot to the sink. All subjects showed a reluctance to let go of these mental models even in the face of contradictory information.

In terms of the experience of using the VE, it was considered to require some concentration, particularly in the beginning; some subjects tended to forget to perform certain actions such as closing the filter holder and putting the water in the machine but remembered after a few trials of finding water on the floor or no coffee in the pot; and only one of the subjects (a patient) considered being video filmed as disturbing

Finally, one of the patients showed a tendency to always click slightly to the right of objects – this might have been due to a slight degree of neglect or a visual problem. The other patient required objects to always be on the right of the coffee machine (which was not possible) so spent quite a bit of time trying to place them there.

6.2 Total Times

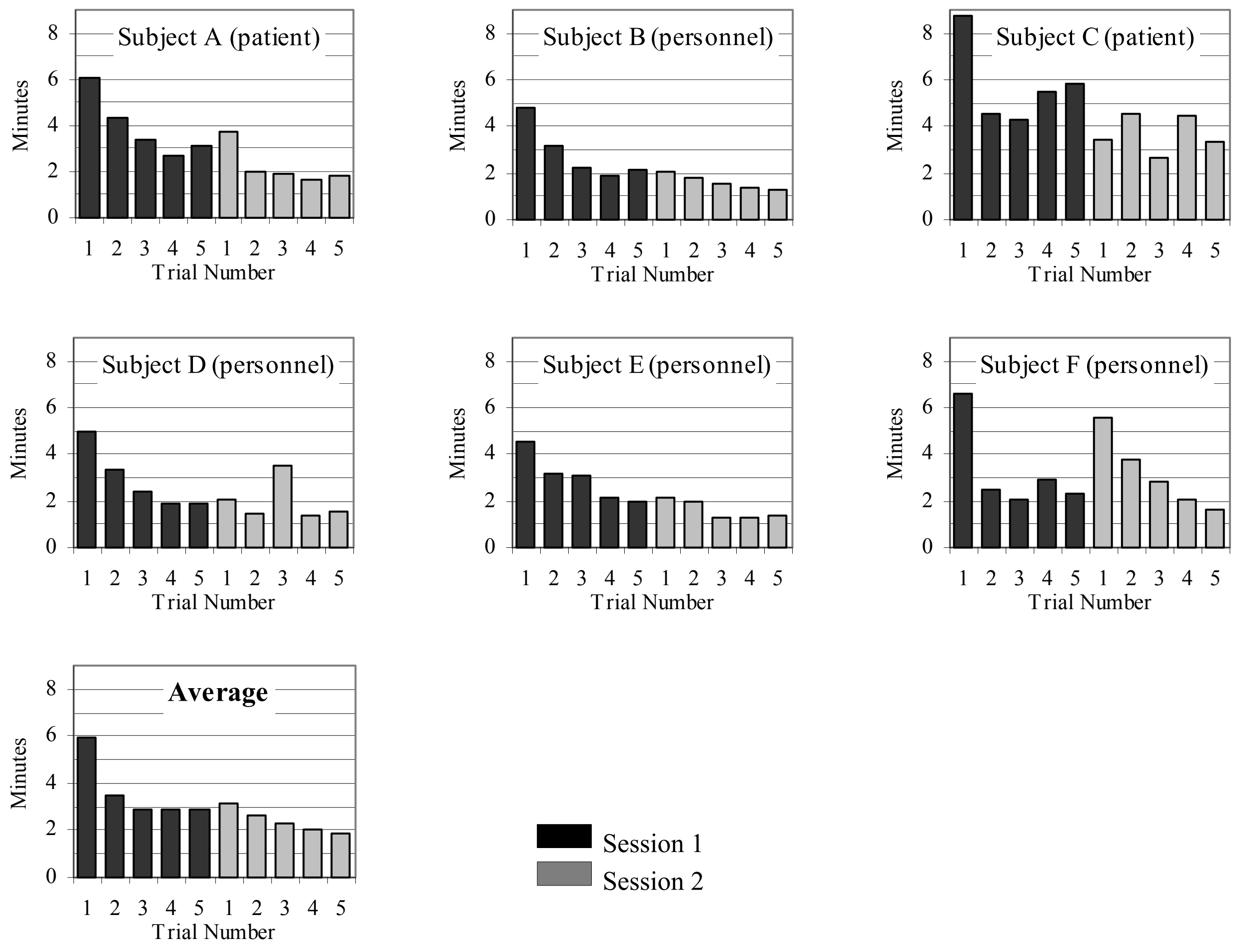

Figure 2. *Total times taken to complete the task for each subject.*

6.3 Comparison with optimal times

Comparing with optimal times (Table 2), the normalised median values for the object activation steps are close to a value of 1, meaning the there was little difference from the optimal times. The percentages of datapoints greater than twice the optimal are also low, signifying that most were less than twice as slow.

For the move object steps, the medians are higher, signifying an increase in time compared to the optimal, and the percentages of datapoints greater than twice the optimal are in some cases over 50%. For the more complex steps, including object-object interaction, the medians are also high, averaging to a time to perform the steps of just under twice that of the optimal times. Almost half the datapoints are greater than twice the optimal.

Table 2: *Normalised medians for task performance of each step*

Interaction Method	Activate			Move		Move + Activate			Complex	
Step Number	2	9	10	1	4	3	6	8	5	7
Normalised Median	0.78	1.00	1.00	2.00	2.00	1.38	1.57	1.33	1.52	2.13
Percentage of datapoints greater than twice optimal	7	20	7	52	51	18	27	25	30	58

7. DISCUSSION

Automatic Navigation appeared to provide no undue problems to the subjects, apart from when a viewpoint position was encountered which made it difficult to click on the next desired object. The main difficulty was when a position was taken close to the bench, but the subject wanted to back away and take a whole view again. A 'back' button might help for this. However, automatic navigation is not always possible whilst still allowing the user free choice in event initiation. For example, If the VE is sufficiently complex so that there are parts that are not visible at all times, then principle 2 is contradicted in that the user doesn't have free choice to initiate events in areas that are not visible, if they cannot navigate themselves there.

Few problems were noted with object activation. Subjects seemed not to be worried that a 'click' was used in situations where in reality one should grasp and turn (such as a tap), or grasp and lift, or push down, as for a switch. In all these situations, the object to be activated appeared the same as in reality and provided immediate feedback of success (such as the tap turning and the water running). The normalised medians showed, in fact, an improvement over the optimal values (since the six best completion times did not necessarily mean that all steps were completed quickly) and most of the subjects completed object activations in a time well less than twice the optimal.

Moving objects, on the other hand, seemed considerably more complicated. The normalised medians show that the time to move objects was almost double that of the optimal times and that steps one and four caused most problems with over half the values being over twice the optimal times. In the videos, it could be seen that the subjects had trouble knowing where to click for step one to move the coffee pot to the sink and step four when the coffee pot should be set on the hotplate, both problems with the sensitive areas. In step four, the subjects often clicked in the area of the coffee machine, however, its shape meant that the centre is actually a gap, and a click there goes through to the bench. The result was that the coffee pot was put down on the bench instead of on the hotplate. To avoid such problems, invisible sensitive areas could be put around such items so that a click in the general vicinity is sufficient. However, sensitive areas cannot overlap, as this would cause confusion.

Oddly enough, all the subjects wanted to drag-and-drop objects around the VE in the beginning, even though this wasn't possible. Whether this comes from having some computer skill, or whether this behaviour is natural cannot be determined, but would make an interesting further study. One subject maintained they had some computer skill, but not of drag-and-drop, though it is difficult to see how that could be the case. If it can be said that drag-and-drop is a natural behaviour and that all people, even those with no computer skill, can manage it, maybe it could be used in the construction of VEs for people with brain injury. All the subjects misunderstood the concept of carrying objects, possibly since it wasn't quite clear that the object in front of the view was currently being 'held'. Perhaps if a virtual hand had grasped the object, this confusion wouldn't have occurred.

Steps three, six and eight, while also requiring objects to be moved were less problematic than steps one and four. Maybe the sensitive areas in the cupboards were more easily fathomed.

Object to object interplay caused some confusion, the main problem resulting from the single-click assumption. With this, it is possible for situations to occur when a click can be interpreted in several ways. This was most apparent when the subjects were putting coffee into the filter. There was little problem in clicking on the filter holder to mean 'put a scoop of coffee here', however, when sufficient coffee had been placed, it was then logical to click on the filter holder to close it. The problem, however, was how to let the computer know this change in mind. Adding the capability for drag-and-drop might help. In this case, coffee could be put into the filter by dragging the scoop to the filter, and the holder closed by a single click. Using the right mouse button for extra functions, though is not desirable as this would complicate the input device considerably.

Considering the total time graphs of Fig. 2, all the subjects had the longest time for the first trial of session one, not surprisingly since they had never used the VE before, then improved for each subsequent trial. In some cases, times started to increase again near the end of session one, perhaps due to fatigue (or boredom). From the analyses of the videos, trial one included many instances of the subjects attempting to understand how to make objects do what they want. When they finally succeeded, this lesson was carried over to the next trial. Subject C, however, was unable to accept that objects could not be placed to the right of the coffee machine and attempted to do this in every trial, despite previous attempts and eventually having to give up.

In session two, all the subjects except subject C showed an increase in time compared to the last trial of session one, suggesting a certain amount of forgetting of what was learnt previously. On average, there seems to be both short term and long term learning effects occurring. The implication is that even if the interface is not perfect, people will learn to compensate, assuming the capacity for learning is not impaired. Subject C, however, demonstrates that even simple things like not being able to place objects to the right of a coffee machine may disrupt the concentration on the task.

Interestingly, nobody complained about reality glitches due to programming VE limitations such as unrealistic water behaviour. It seemed sufficient that the end states for each action were correct, rather than how objects interacted to get there. So, for example, the water from the tap doesn't meet the surface of the water in the pot when filling, but water appears there anyway, and the pouring of the water into the machine occurs without seeing the water go between. In these cases, it might be however, the sound effects that fill the visual gap. Subjects had more problem with remembering that the coffee machine was of a different model to that they were used to.

8. CONCLUSION

In the design of a VE system for use by people with a brain injury, it is essential to carefully consider all aspects of the system design, from the input and output devices to the contents and structure of the VE itself. Every aspect can potentially have a negative effect on the cognitive abilities of the user, which for a person with brain injury may make the VE unusable.

With this in mind, we have evaluated the effect of design decisions for a VE system intended as a complement to existing techniques for assessment of cognitive function. The following conclusions can be made:

- People seem to have an inherent understanding for click-to-activate and drag-and-drop (this was the case even for the two subject with brain injuries).
- Moving objects poses some problems though, mainly in choosing where to click the mouse to place the object. The users' mental models of real world objects appears to aid in deciding which objects afford being clicked upon in the VE for activation. However, for object placement, the mouse-click means "place there", an apparently less logical concept. Perhaps some visual cue may help.
- The automatic navigation technique works well for situations where the VE is not too large to be viewed in one screen-full, though some situations can occur when a key would be useful for returning to some overview position. As navigation was hardly noticed by the subjects, it would be ideal for VEs to be used by people with a brain injury, though not in too large environments.
- Problems can occur when a mouse-click can be interpreted by the computer in several ways, though it may be possible to resolve these with clever programming and alternative interaction metaphors.
- A certain amount of imprecision must be allowed in the sensitive areas for object interaction. For example, when an object is small on the screen, being able to click in its general vicinity should assist the interaction process. Similarly, people seem to like to click in the middle of objects, so if there is a hole there, maybe an invisible sensitive area would help.
- When carrying objects, it is essential that it is clear that the object is being carried, perhaps by having a hand holding it.
- The users' mental models can affect the usage of the VE. Firstly, disparities between virtual objects and real ones the user is accustomed to can cause misunderstandings. Secondly, expectations in how the VE itself works, if wrongly made, can cause confusion. The main problem is when actions allowed in reality are not permissible in the VE.
- Persistent mental and physical problems of the users were apparent from the analysis of the videos. These showed, in one case, a rigidity of mental model and a possible physical problem in another. Therefore, using such a VE in this manner, recording the users' actions and screen view, and performing a detailed analysis could be developed into a workable assessment tool for brain injury rehabilitation.

- The patients and one of the personnel showed a tendency to become tired after performing the same task a few times. However, all the subjects managed to perform the task within acceptable time limits, thus showing that a VE tool could well be usable for rehabilitation.

Further work is planned to look into other forms of viewpoint navigation and the effect of the input device on usability as well as transfer of training effects and the development of a number of complementary VE applications for brain injury rehabilitation. For navigation, the interplay between the number of degrees of freedom and the type of input device will be investigated. For object interaction, the use of drag-and-drop and whether a virtual hand to hold objects will simplify object movement will be investigated.

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Session XI. Cognition

Chair: Paul Sharkey

Virtual city for cognitive rehabilitation

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ABSTRACT

Virtual Reality technology offers opportunities to create new products, which could be applied to the cognitive rehabilitation of people with acquired brain injury or neurological/psychiatric disorders. The effects provided by Virtual Environments (VE) stimulate cerebral neuroplastic changes, enhancing the rehabilitation process. This article discusses issues related to this field and presents the main features of an Integrated Virtual Environment for Cognitive Rehabilitation development process. Finally, initial results of an experiment with a group of schizophrenic patients are presented.

1. INTRODUCTION

Nowadays the medical practices allow an increase rate of survivors from traumatic brain injuries and diseases affecting the CNS (Moline,1997). New medications for neuropsychiatric patients are also diminishing the percentage of hospitalization and are promoting the permanence of these people at their home. These changes stimulate the development of new therapeutic approaches that integrate basic elements of social life and contribute to enhance the life quality of these people. Nevertheless, in all these cases, the therapy takes a long time, the support material is expensive and the construction and maintenance of the real environments is complex. The combination of all these factors creates a barrier that makes it difficult to access and diffuse therapeutic practices to a greater number of people (Costa,2000).

These questions are stimulating the researchers of variable fields to search new options for rehabilitation of people with disabilities. In this context, the computer has been explored by different kinds of software that reproduce, basically, the neuropsychological tests or traditional rehabilitation procedures (Digit,1996), (Shapes,1996), (Pipeline,1998). However, we observe that specific results of the experiments are not published, creating problems in order to make a more accurate assessment to these products.

Recently, Virtual Reality (VR) based software are thought to be potentially more representative of every-day life situations than paper-and-pencil treatment procedures or limited software (Pugnetti,1998). VR provides opportunities to enlarge the actual limits of mental health applications providing valuable scenarios, with common elements for the patients, putting them in contact to daily life activities.

Although Virtual Reality immaturity and high costs of equipment, some results points this technology as a new possibility to rehabilitate cognitive and motor functions, stressing its characteristics as a motivator factor.

So, VR can amplify the therapeutic possibilities by virtual environments with exercises that stimulate a variable kind of abilities, proposing similar tasks, alike real life. Another positive factor of this technology is that Virtual Reality integrated in the WWW could disseminate virtual therapeutic environment to small villages far from urban centers or where economic problems do not allow the construction of real scenes.

Starting from several technical and theoretical factors involved in the conception of a product for treatment of brain disorders, this article will describe a virtual environment (Ambiente Virtual Integrado para Reabilitação Cognitiva - AVIRC) that explores therapeutic strategies and can act, in an integrated way, in different types of cognitive disorders, offering significant opportunities to the patients to face common day-to-day situations.

In the next sections we will present the basic characteristics of virtual reality technology discussing the brain plasticity theory that supports ability recover, illustrate the discussion with some cognitive rehabilitation experiments and propose AVIRC. Finally, we will describe the initial results of an experiment with a group of schizophrenic patients.

2. VIRTUAL ENVIRONMENTS

Virtual Reality includes advanced technologies of interface, immersing the user in environments that can be actively interacted with and explored. The user can also, accomplish navigation and interaction in a three-dimensional synthetic environment generated by computer, using multi-sensory channels (Pinho,1999). In this case, diverse kinds of stimuli can be transmitted by specific devices and perceived by one or more user's senses.

There are three fundamental ideas involved in VR: immersion, interaction and presence. Immersion can be achieved by the use of HMD (head mounted display), trackers, electronic gloves, that support user navigation and interaction, supporting the exploration of the environment and the manipulation of objects in an easy manner. Interaction means communication between the user and the virtual world. Presence is a very subjective sense that the user is physically inside of the virtual environment, participating in it.

So, a Virtual Environment is considered to be a three-dimensional, real-time graphical environment synthesized by a computer, in which the viewpoint or the orientation of displayed objects are controlled by the user via body position sensors or user-input devices (Lewis,1997).

3. COGNITIVE REHABILITATION BY VIRTUAL REALITY TECHNOLOGY

Virtual Reality applications have some interesting results based on environments that work with specific disabilities related to mental problems or motor problems, as can be observed in: Treatment of phobias (North,1998); Manipulation of wheel chairs for children (Inman,1997); Body image disturbances (Riva,1998); Head injury (Christiansen,1998); Parkinson disease (Riess,1995), and Autism (Stricland,1997), among others. As a psychological approach, there have been experiments to help cancer patients accept their disease (Oyama,1997). For attentional retraining and perceptuo-motor skills reacquisition, there has been work by Wann et al. (Wann,1997).

These pilot studies sought to discuss and experiment with the possibilities offered by VR technology. In these contexts, VR is allowing therapeutic practitioners to help their patients in a number of innovative ways, offering new approaches to old questions and increasing the effectiveness of consolidated methodologies.

Therapeutic change may occur either through the reacquisition of cognitive abilities via repetitive, systematic, hierarchical restorative cognitive stimulation or by teaching alternative compensatory strategies that target actual task performance (Rizzo,1997). Another fundamental issue, which has important implications regarding the feasibility of a VR approach applied to cognitive rehabilitation, concerns the concepts of transfer or generalization of functions. In this case, the environment would stimulate transfer from the training environment to day-to-day functioning. The principal objective of every rehabilitation program is generalization that promotes autonomy and independence. In this work, generalization is related with pedagogical issues and associated strategies to keep learning process more effective.

3.1 Plasticity in Rehabilitation

Brain plasticity can be taken as any behavioral modification that results from environmental stimulus change. The central nervous system is able to learn new behaviors, adapt to changing environmental situations, acquire memories and mature with the organism (Schwartzkroin,1989). In this sense, neural plasticity ability supports the cognitive rehabilitation procedures and VR provides resources to augment interactive experiences.

From the results of experiments in this field we perceive that among different functions that emerge from neurons interaction, the ability of learning and exploit memory can be influenced by external factors. So, the possibility of brain plasticity from environmental stimuli is essential to therapeutic strategies development to many cerebral disorders.

3.2 Schizophrenia

Schizophrenia is a serious psychiatric illness that can involve massive disruptions of thinking, perception and behavior, and is not yet cleared up by science. Its prevalence rate is about 1% of world population. This disease is characterized by pervasive impairment in social, cognitive, affective, and daily functioning. The more common deficits are associated to attention, information processing, memory, learning and executive functions (Cassidy,1996).

In the related literature we can find studies about psychiatric disorders and associated experiments with computer software. Not always the results indicate that the psychiatric patients can work productively with computers (Field,1997), but there are some that confirm the positive computer influence to enhance the cognitive performance of these people (Burda,1994). In all these cases, they worked with simple software on a flat-screen. We haven't found cognitive rehabilitation experiments using VR equipments to work with schizophrenic patients.

So that, two main aspects have supported this work: first of all, we searched a virtual environment that could be used to stimulate the fundamental cognitive functions that compose the elaborated activities for different nature of disabilities. Second, we verified if schizophrenic patients could use this environment to learn and train lost abilities, individualizing this process to meet the needs of each patient.

4. AVIRC: INTEGRATED VIRTUAL ENVIRONMENT FOR COGNITIVE REHABILITATION

AVIRC presents an unified workspace: a city. It focuses on cognitive processes training such as attention and concentration, and functional skill training such as executive functioning in everyday life. AVIRC is composed of a square surrounded by streets and several types of constructions: houses, stores, a library, a church, small buildings and a supermarket that can be freely visited by patients. Some characteristics of AVIRC development are discussed in the following subsections:

4.1 Motivation

Usually, VR experiences in cognitive rehabilitation are restricted to a specific disabilities set. In general, we observed that examples work with punctual functions related to each disability, acting mainly in attention, memory, motor abilities and using challenging strategies, common to educational games. In respect to the integration of transfer and generalization concepts, it is verified that in many experiments this aspect remains to be solved.

The above considerations have guided this research towards a proposal that embodies different integrated cognitive function stimuli, respecting interdependence between them and information processing.

Based on these observations, we have searched for an environment that could be used in the treatment of different brain disorders.

4.2 Objective

The main aim of this research led to the design of an interactive tool to support cognitive ability recover for people with different cerebral disabilities, exploring learning strategies and offering opportunities for expressive experiences with day-to-day situations.

4.3 General requirements definition

This environment is based on neuropsychology, psychology and neurology, and considers the recuperation of cognitive functions and executive functions. In this case, cerebral plasticity, therapeutic strategies for cognitive rehabilitation, technical aspects and experimental results of similar works are considered in the construction of this environment. We also consider, pedagogical aspects of recognized theories: some tasks support a restorative approach, with a behavioral emphasis; other tasks involve the integration of cognitive functions, under a more constructivist functional approach (Costa,1999).

In Table 1 we define virtual environment based on a framework that detail its fundamentals components and main characteristics.

4.4 Specific requirements definition

In this environment the patient can accomplish different tasks, carefully associated to the therapeutic procedures used for the rehabilitation of specific functions, and aiming to offer transfer and generalization opportunities. In Table 2 some tasks and the appearance of the associated physical environments are briefly described.

4.5 Prototyping

The prototype was built using VRML (Virtual Reality Modeling Language) that provides three-dimensional worlds with integrated hyperlinks that can be put on the Web. The programming is supported by Internet Space Builder and Internet Scene Assembler software (Parallelgraphics®), and the interaction was programmed in JavaScript.

The scenes can be visualized on a web navigator (ex:Netscape® or Explorer®) with a plug-in (ex:Cortona®). In figures 1, 2 and 3 some scenes of version 1.1 are presented.

Table 1: *AVIRC description framework (Costa,2000b)*

Characteristics	AVIRC
Therapeutic approach	Restorative and functional
Disorders	Psychological, Psychiatric and Neurological
To make possible	Transfer and generalization
Cognitive Functions	Alertness, attention, concentration, perception, memory and executive functions
Equipment	PC Pentium III 450 with a graphical accelerator device, I-Glasses and a head position tracker
Interaction model	1st moment: subjective immersion 2nd moment: spatial immersion
Interaction degree	1st moment: low 2nd moment: medium/high
Interaction equipment	1st moment: flat-screen 2nd moment: I-glasses with a head motion tracker

Table 2. *AVIRC's description of tasks*

Cognitive Function	Physical Environment Description	Task Description
Alertness	A house room with many decorative elements: clock, photos, pictures, calendar, background music	Answer the date, hour, turn on/off the radio and the lamp
Concentration	Clean music room without ornamentation contains a piano with colored keys	Hear and repeat a sequence of musical notes associated to colored keys
Attention	Game room contains books and games.	Solve different puzzles and choose books, guided by some clues
Perception	In the street several people are walking	Look at cards with people's photos and identify those that have already been seen
Memory	Street contains a public telephone and several traffic signals	Reach the telephone and dial a number starting from oral and written requests

4.6 Experiment

Some initial experiments are being carried out with a group of schizophrenic patients to test AVIRC acceptance. These patients participate in a treatment program of a public day-hospital, where they spend all day and at night they go home. They develop a lot of activities as arts, games, sports, music and recently, computer classes. To make this research we had to submit a project to an ethical committee, according to Brazilian Health National Council.

In this study, we are interested in observing if the patients accept the VR technology and respond to virtual environment tasks in a meaningful way. The initial experiments consider three stages:

1 - Integration of the patients with the computer;

2 - Flat-screen virtual environment acceptance;

3 - Immersion equipment acceptance.

We have a group composed by 5 patients and we are at the end of the first stage. All group members are accepting computer sessions and show a growing enthusiasm. The initial results indicated that patients were self-adapting to technology, which allowed us to proceed to second phase.

On the first attempt, they were a little surprised with the colors and objects composing the scenes. They are very motivated and no absence was observed on the two first sessions. They are very curious about the I-glasses. We will only verify cognitive gains during the fourth stage.

Figure 1: *Music Room.*

Figure 2: *Partial view of the city.*

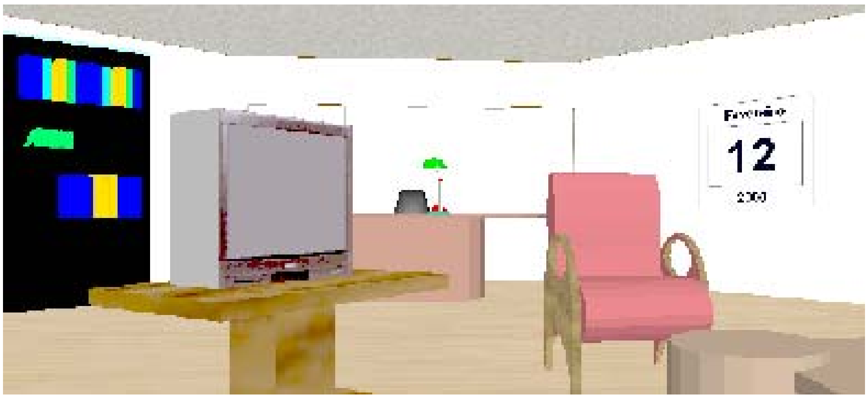

Figure 3. *Alertness room view.*

5. CONCLUSION

This paper presented an Integrated Virtual Environment for Cognitive rehabilitation (AVIRC), stressing possibilities for using in cognitive rehabilitation of people with different cerebral problems.

The main characteristics presented here were defined starting from the study of neuropsychological procedures for treatment of different types of brain disorders. Unlike the commercial products available today, this environment explores some traditional tasks under a more constructivist focus, following the current pedagogic tendencies and integrating rehabilitation strategies for different cognitive functions. The use of VR technology, with an interface close to reality, could reduce the gap between patients and daily life tasks, decreasing fear of errors.

The research described in this work as well as numerous studies going around the world indicate that virtual environments may be of great value in helping individuals principally when training them to live better in the real world.

The initial results with a group of schizophrenic patients indicate that they accept the VR technology and they are very enthusiastic to work with computers. However, the use of this technology in cognitive rehabilitation of schizophrenia merits further research to determine functional relationships between the virtual environments and cognitive gains.

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Peripheral responses to a mental-stress inducing virtual environment experience

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ABSTRACT

Virtual environments (VEs) are used increasingly in the education and training of people with disabilities. When utilizing these VEs, it is important to know 1) whether they are effective in the manner desired and 2) whether there are side effects from them. This exploratory study looks at both issues. This paper describes a study in which we observe a predictable pattern of both stress related to the content of the VE and a pattern of relaxation over time (30 minutes – 1 hour) in the VE.

1. INTRODUCTION

When using a virtual environment (VE) for the education and training of people with disabilities, it is important to know whether the VE is effective and whether it produces undesired side effects. This paper discusses a study that looks at both issues: Are there noticeable side effects from the virtual environment, and can a VE produce a predictable physiological stress response?

Since the mid 1980's, researchers have been laboring to make virtual environments work well and to reduce the side effects from VEs. One of the keys to making virtual environments work well is engaging the user in the content of the VE. The key to reducing the side effects of VEs is presenting to the user the information that they expect: proper visual information, low movement lag, high frame rate, etc…

In this study we look at whether the content of the VE can evoke predictable physiological stress response. We also look for a stress response produced by simply engaging in the VE. Sixteen subjects were instructed to navigate the ARCANA virtual environment – a VE version of the Wisconsin Card Sorting Test. The environment became more difficult to navigate after each room (via the introduction of visual fog in the VE), and incorrect navigation triggered additional fog and the sound of a gunshot accompanying a virtual soccer-ball in the face (see figures 1 and 2).

We found that the content of the VE evokes a predictable stress response in the participants of the study. We interpret this predictable pattern of stress response as the subjects engaging in the content of the virtual environment – the VE is effective. The ability to produce a predictable stress response and the fact that users can be engaged in the virtual environment for a long period of time without physiological side effects (other than the stress response evoked by the content) gives us confidence that physiological response can be used to monitor reaction to the content of a VE.

Since we can monitor physiological reaction to the content of a virtual environment, it might be possible to use physiological reaction to gauge how believable a virtual environment is for a user: how *present* a user is in the virtual environment.

These findings provide a basis for the research direction: "Can physiological response be used to measure presence in virtual environments?" This serves as a cornerstone for this research by showing that physiological response can be used to measure reaction to the content of a virtual environment and that users do not have a confounding physiological reaction to simply engaging in the VE for a long period of time (30 minutes – 1 hour).

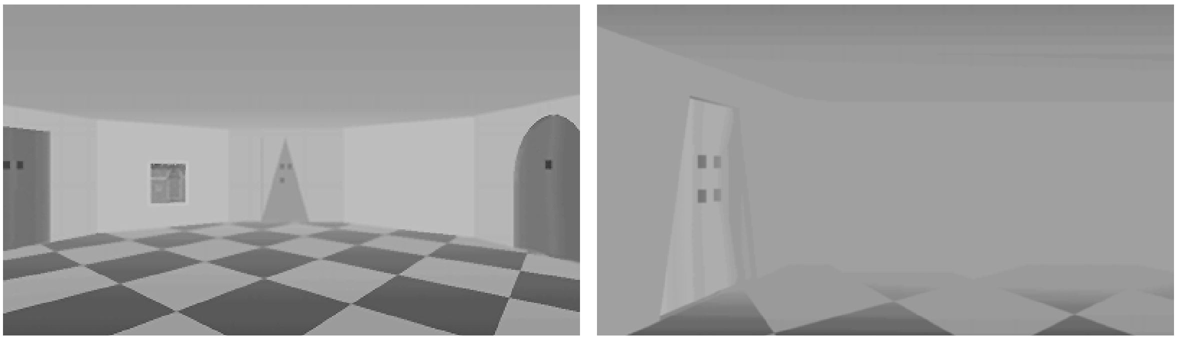

Figure 1. *The environment with little fog (left) and with debilitating fog (right).*

Figure 2. *Soccer ball in the face is accompanied by the sound of a gunshot. Occurs when a user makes an incorrect door choice.*

2. THE ENVIRONMENT

As in (Pugnetti et al, 1995), our VE was an electronic version of the Wisconsin Card Sorting Test (WCST). It was built using Superscape's Virtual Reality Toolkit and ran under Superscape Visualiser version 5.60 on an Intel Pentium II 400 MHz processor running Microsoft Windows 98. A Neuroscan 32 system was used to monitor neurological and physiological responses. A joystick was used for navigation, and the image was projected at 640x480 to (approximately 1 meter x 1.35 meter).

We had 16 users navigate a virtual building in as short a time as possible. Participants moved from room to room by selecting an exit door. Before selecting an exit door, subjects position themselves in the center of the room and face the entrance door. This closes the entrance door and "unlocks" the exit doors. The cue for selecting the correct exit door is obtained by looking at the entrance door. There are three potential categories for correct door choice – matching the color, shape, or pattern of the exit door to that of the entrance. There are 32 rooms.

Once an exit door is chosen, it opens onto a hallway at the end of which is an unmarked door. If the choice is correct, the unmarked door opens to the next room. If the door is incorrect, the participants hear a gunshot and see a virtual soccer ball come directly at them as they entered another hallway (see figure 2). Participants are instructed to press the joystick's trigger upon seeing the ball.

At some point for each subject, the fog becomes *debilitating* - they can no longer see the entrance door (or any other door) from the center of the room. Before the fog becomes debilitating, a correct exit choice increases the fog slightly, and an incorrect exit choice increases the fog greatly. After the fog becomes debilitating a correct choice decreases the fog slightly, and an incorrect choice increases the fog. The fog only increases to the point where the subject can see a virtual arm's length. Once the fog reaches the point of debilitation, it never recedes beyond that point - regardless of the number of correct door choices. Debilitating fog is reached at 9-15 incorrect door choices. Figure 1 depicts a low fog and a debilitating fog situation. In figure 2, both views have no fog.

3. RESULTS AND DISCUSSION

We monitored subjects' physiological and neurological responses while in the environment. This paper discusses the physiological responses: heart rate (EKG) and skin potential. A companion paper, (Pugnetti et al, 2000) discusses the neurological responses. We monitor heart rate (via EKG) and electrodermal activity (via skin potential level and skin potential reactions). These measures have been seen to vary due to fear: heart rate increases, and skin potential increases. (Weiderhold et al, 1998), (Andreassi, 1995) For general information on measuring and interpreting skin potential and heart rate, please see (Andreassi, 1995).

1. *There is a significant decrease in the percentage change skin potential level (%ΔSPL) predicted by the number of rooms traversed and there is a significant increase in %ΔSPL predicted by the number of incorrect door choices. Additionally, there is a reduction in the predicted effect of number of incorrect rooms on %ΔSPL once the virtual fog is thick enough that the subject can not see the doors from the center of the room.*

We measure skin potential level (SPL) as the average skin potential level recorded in the first minute of each room. Percentage change skin potential level (%ΔSPL) is calculated as the percentage change of SPL as compared to the first room. The corrected model is constructed using SPSS 10.0.1 for Windows with 5% as the entry cutoff for variables and 10% as the removal cutoff. The cutoff for model significance is 5%. The resulting model is then analyzed using SPSS's univariate GLM with parameter estimation. Table 1 is a reduced version of the generated tables.

Table 1. *Tests of Between-Subjects Effects: Percentage change skin potential level.*

Source	Parameter Estimate	F	Sig.
Corrected Model		4.381	.000
Intercept	-382.656	13.877	.000
SUBJ	(Different for each: +134..+411)	4.876	.000
# room traversed (#R)	-4.962	2.879	.091
# incorrect choices (#IC)	16.759	3.659	.057
#incorrect choices * (0=less fog, 1=debilitating fog) (#IC*FD)	-8.528	4.096	.044

Table 1 shows that the corrected model is significant at <0.1%. The parameter estimates suggest that, after correcting for between-subject differences in intercept, %ΔSPL decreases with number of rooms traversed (#R) and increases as subjects make incorrect choices (#IC). Additionally, the effect of number of incorrect choices on %ΔSPL decreases after the fog in the environment has reached the point where the subject can no longer see the doors from the center of the room (FD – fog is debilitating).

We interpret the decrease in %ΔSPL with #R as a subject's ability to relax in the environment. This is an interesting finding since the subjects were not only subjected to a virtual environment for an extended period (between 30 minutes and 1 hour), but because they were covered with physiological and neurological monitoring equipment. We believe that this finding supports the theory that virtual environments and physiological monitoring equipment are not overly stress producing. That is, subjects who do not regularly use virtual environments can show signs of relaxation over time when exposed to the environment even when they have an ostensibly uncomfortable arrangement of wires are connected to them. Before the experiment, we recognized that either discomfort from the monitoring equipment or the novelty of the virtual environment might be stressful for the participants or otherwise impair our results. We believe these data support a theory that subjects are able to relax in spite of the monitoring equipment and the novelty of the virtual environment.

We interpret the increase in %ΔSPL with #IC as the subject reacting to the content of the virtual environment. This supports the theory that the environment is engaging and that the engagement evokes physiological stress response that follows patterns predicted by reactions to similar real situations.

The interaction between #IC and FD suggests that there is a decrease in physiological reaction to incorrect choices once the task becomes difficult. The subjects need to stand in the center of the room to close the entrance door. Once they can no longer see the doors from the center of the room, it is easy to become disoriented (little to no feed back on position from the center of the room) and frustrated (makes it difficult to close the entrance door). Figure 1 illustrates low and debilitating fog. Also, with much fog, subjects loose the ability to see the entrance door, which they use to determine the correct exit door. This makes the task more difficult because they must memorize the original door and navigate the room in order to make a decision. We interpret the decrease in #IC's effect on %ΔSPL once the fog becomes debilitating as a sign that subjects become less concerned about correct choices once navigation becomes sufficiently difficult and simply try to traverse the rooms as best they can.

2. *There is a significant decrease in the percentage change heart rate (%ΔHR) predicted by the number of rooms traversed and there is a significant increase in %ΔSPL predicted by the number of incorrect door choices when the fog is not debilitating.*

Heart rate (HR) is measured as the average HR recorded in the first minute of each room. Percentage change heart rate (%ΔHR) is calculated as the percentage change of HR as compared to the first room. The corrected model is constructed using SPSS 10.0.1 for Windows using the method described above. Table 2 is a reduced version of the generated tables.

Table 2. *Tests of Between-Subjects Effects: Percentage change heart rate.*

Source	**Parameter Estimate**	**F**	**Sig.**
Corrected Model		3.658	.028
Intercept	-2.056	3.492	.063
# rooms traversed (#R)	-.182	7.173	.008
#incorrect choices * (1=debilitating fog, 0 otherwise) (#IC*FD)	.170	3.162	.077

Table 2 shows that the corrected model is significant at <5%. The parameter estimates suggest that %ΔHR decreases with #R and increases with #IC when the fog is not debilitating. The addition of subject to the model approached significance.

As with %ΔSPL, we interpret the decrease in %ΔHR with #R as a subject's ability to relax in the environment. This further confirms our theory that virtual environments and physiological monitoring equipment are not overly intimidating or stress producing. Subjects who do not regularly use virtual environments can show signs of relaxation over time when exposed to the environment even when they have an ostensibly uncomfortable arrangement of wires are connected to them.

We interpret the increase in %ΔHR with #IC when not FD as the subject reacting to the content of the virtual environment. As with %ΔSPL, this supports the theory that the environment is engaging and that the engagement evoked physiological stress response that follows a predictable pattern.

The significance of the interaction between #IC and FD suggests that there is little to no physiological reaction once the task becomes difficult. As described above, when the fog becomes debilitating, the task becomes difficult enough that subject may no longer be concerned with finding the correct choice, but only interested in completing the task.

3. *The amplitude of skin potential reactions significantly increased with number of incorrect choices.*

Skin potential (SP) is measured as the difference between the negative and positive components of the skin potential reaction when an incorrect door was chosen. An SPR generally occurs within 2-5 seconds of stimulus and is characterized as a wave with a negative and positive component. A typical SPR is illustrated in figure 3.

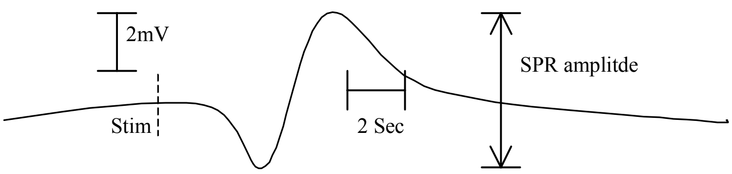

Figure 3. *A typical skin conductance reaction.*

Percentage change skin potential reaction (%ΔSPR) is calculated as the percentage change of the amplitude of the SPR as compared to that of the first incorrect choice. The corrected model is constructed using SPSS 10.0.1 for Windows using the method described above. Table 3 is a reduced version of the generated tables.

Table 3. *Tests of Between-Subjects Effects: Percentage change skin potential reaction.*

Source	Parameter Estimates	F	Sig.
Corrected Model		3.544	.000
Intercept	15.462	11.715	.001
# incorrect choices (#IC)	5.508	4.998	.028
SUBJ	(Different for each: -33..181)	3.314	.001

The corrected model is significant at <0.1%. After correcting for between-subject differences in intercept, there was a significant increase in %ΔSPR as subjects made more incorrect choices. We interpret this finding as subjects becoming more frustrated (more SPR reaction) as they make more incorrect choices. This further supports the theory that the environment was engaging and can evoke physiological response in a pattern predictable by real-world reaction.

4. CONCLUSIONS

Overall, these finding suggest that the content of a virtual environment can evoke physiological response in a predictable pattern. It also supports the belief that the technology associated with the VE and the physiological and neurological monitoring equipment neither impedes the understanding of the content nor confounds the results of content-based stress production.

5. FUTURE WORK

This study provides the base for four studies (three have been completed; one will soon be conducted) that investigate the use of physiological response to assess presence in virtual environments. Presence has been defined as the user feeling that *the experience is more like a place visited and not just a series of pictures seen* (Slater et al, 1995). In these follow-up experiments, the VE passively evokes a stress response. Physiological reactions and other measures of presence are used as metrics to determine what technological advances in virtual environments are important in making a virtual environment engaging. System factors under investigation include better frame rate and use of near-field static haptics. The firsts of these follow-up studies was presented at Presence 2000 in Delft, the Netherlands. (Meehan, 2000) This is the focus of the first author's Ph.D. dissertation work.

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More on central nervous system correlates of virtual reality testing

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ABSTRACT

Polygraphic recordings of EEG and peripheral variables of 10 healthy volunteers taking a VR-based cognitive testing were analysed to describe the phenomenology of short-term and long-term EEG and EP changes and to extract psycophysiological indicators of information processing and adaptation. A non-immersive VR set-up was used to allow exposures to VR of up to 60 min. Auditory-task irrelevant probes proved effective in tracking participants' mental fatigue. Strong negative feedback and motor reactions to them produced well formed event-related potentials including anticipatory components, while other ERPs and alpha EEG changes were noticed to be associated with specific VR events. Finally, sustained EEG changes took place which were correlated with successful or failing cognitive strategies. The neurological equipment produced only negligible additional discomfort to the participants. Psychophysiological investigations should be carried out more intensively by those developing applications for the disables because are potentially very informative and suitable to tune and optimise important aspects of VR-based paradigms.

1. INTRODUCTION

Virtual environments (VE) are increasingly proposed to assess and treat psychophysiological and cognitive-behavioral disorders (Rose et al., 1997; Rizzo et al., 1997), but surprisingly little is known about their ability to induce transient or sustained psychophysiological modifications in exposed individuals. Knowledge about changes in recordable brain activity may serve several purposes, such as tuning the intensity, the frequency, the timing of a given combination of stimuli to the desired level for a given category of users. On the other hand, VEs can provide psychophysiologists an opportunity to experiment new ways of studying human adaptation in more ecological, but nontheless controlled, conditions. We have suggested (Pugnetti et al., 1996) that psychophysiological studies should precede the clinical application of a VR product to better understand its impact on subjects' physiology and to avoid missing important – either favourable or evil – consequences of exposure to it. The attempt to combine psychophysiological monitoring to VR research, however, is not new. In 1993, Eberhart and Kizakevich briefly described their experiments with healthy volunteers performing tracking tasks in an virtual environment, but gave no precise account of results. Our group (Pugnetti et al., 1994, 1995, 1996) carried out pilot EEG and evoked potentials (EP) studies with an earlier immersive version of our neuropsychological virtual testing scenario, and we were able to show that neat recordings are possible even when subjects wore CRT headsets and magnetic tracking sensors. Nelson et al. (1997) recorded the EEG from subjects interacting with a VE projected on a large screen, which indeed reduces potential sources of interference and the amount of cabling around the subjects. VR is also being implemented into traditional EEG biofeedback in an effort to enhance treatment of specific psychophysiological disorders (Kaiser and Othmer, 2000). A collaboration with UNC has recently given us the opportunity to considerably expand our previous observations, as the ARCANA software has been modified to connect with a new recording equipment and to produce additional stress to the users by degrading the visibility as the number of errors increases (see also Meehan et al., this volume).

2. AIMS AND RATIONALE

The principal aim of this report is to complete the description of the variety of CNS correlates recordable from healthy adults. The paradigm (a classic card sorting test) and the virtual version we devised (Pugnetti et al., 1995) lend themselves to record transient brain responses (event-related potentials (ERPs), electrooculographic patterns (Eog), phasic EEG rhythmic responses) and tonic EEG changes. In principle, however, any VE can be viewed as a tool to provide complex information and evoke brain responses. Different types of environments, therefore, convey different information and require different types of processing. A combination of a few basic types of VEs that repeats itself a number of times gives the opportunity to record repetitive changes in brain electrical activity due to transient stimulation along with changes that are associated with more durable events such as adaptation to the experimental conditions, learning, and fatigue. We were primarily interested to see whether the EEG reflects the informational content of our two main types of VEs: rooms and hallways. Second, we looked at EP to task irrelevant stimuli as possible indicators of mental adaptation or fatigue during a long lasting exposure to VR, and last, we sought confirmation of our earlier studies on event-related potentials.

3. METHODS

3.1 Participants and procedures

We had 16 healthy volunteers participate in this new experiment; data from 10 of them will be considered here. There were 4 females aged 29.7 ± 3.2 yrs, and 6 males aged 29 ± 4.0 yrs., recruited from the hospital staff, their friends and relatives. Subjects signed an informed consent and were allowed to terminate the session should they feel any discomfort. Before and after the VR session they filled in questionnaires concerning their feelings, symptoms (Regan and Price, 1994) and experience with the system. Subjects were isolated from the recording equipment and handled a joystick while sitting in front of a large (1x1.35 meter) screen on which the VE was projected. To avoid artefacts as much as possible, they were asked to limit sudden gross body movements during the experiment. Before starting, they were hooked up, then calibration procedures took place after which they were given a 10 min practice run that served also as baseline for some of the measurements. The experimental task was to navigate a virtual building in as short a time as possible, as described elsewhere (Mendozzi et al., 1998; see also Meehan et al., this volume). Significant events were classified according to previous studies with the same paradigm and triggers released accordingly. They were used for off-line computation of averaged evoked responses and the identification of continuous EEG epochs between two significant events. Stimuli were both visual and auditory. A constant background auditory stimulation with 1500 Hz pure tone pips of about 95 dB nHL was given at a rate of 1.2/sec by two loudspeakers located at a distance of about 2 m. in front of the subjects. Tones served as irrelevant probes to compute auditory evoked responses (AERs) to assess how much subjects were able to concentrate on the main task (Kramer et al., 1995). Task-relevant auditory stimuli (gunshot sounds) were also released at the time of feedback following wrong matches; they were used to compute event-related responses along with any presses of the joystick trigger upon seeing the ball. Any opening/closing of doors and any passage from one environment to another was also marked as a relevant stimulus or event.

3.2 Data recording and processing

We recorded 5 unipolar EEG leads (Fz, Cz, Pz, P3 and P4 all referenced to linked earlobes), 4 unipolar EOGs, 2 dominant forearm arms and 1 facial bipolar EMGs, and peripheral channels as discussed by Meehan et al. (this volume). Signals were sampled at an AD rate of 1000 Hz/channell by a Neuroscan 32 system and monitored both on screen and on paper for the whole duration of the experiment (30 to 60 min. depending on the individual performance). Precise correspondence between physiological events, virtual stimuli and behavioral responses was insured by triggers released by the VE server and recorded along with body signals and videos of the subject and of the VE. Any off-line computation was preceded by appropriate digital filtering and removal of artifacts. A total of 10 recordings were found to contain good quality continuous EEG tracings and were therefore used for this report. Additional data will require further editing due to heavier contamination by artifacts.

4. RESULTS

4.1 AERs to irrelevant probes

Auditory N1-P2 components (peaking at about 100 and 150 ms. from stimulus onset) could be retrieved from the background EEG of all the 10 subjects selected for this analysis. These EP are of supratentorial (mainly cortical) origin but in normal hearing vigilant subjects can be considered as obligatory or automatic responses and are known to be modulated primarily by the physical characteristics of the stimuli. Endogenous factors, however, may also influence their expression to some extent. The AERs recorded during a 3 min. baseline period when subjects practiced with navigation on a demo-VE had greater mean amplitudes than the same waveforms recorded during a 3 min. period after completion of the VR test when subjects navigated a different VE with no specific instructions (Figure 1 and table 1). Potentials recorded midway during the VR test did not differ significantly from the baseline period. The amplitude of the N1-P2 components measured at the Fz site was especially reduced post-test. The latencies of the principal components of the AER was not changed except for P1 latency which tended to increase after the test (table 1). Two subjects, however, showed clearcut mean N1 latency increases exceeding 10 msec. after VR. All but one subject reduced N1-P2 amplitude after testing. The drop in mean AER amplitude was predicted as a result of previous pilot studies (Pugnetti et al., 1996). The change in brain potentials we observed are comparable to those produced in a relaxed subject by a decrease from optimal level of approximately 30 dB of the intensity of a repetitive short auditory stimulus. The difference between baseline and post-test N1-P2 amplitude correlated with the number of errors made during the VR test (Pearson's coefficient r =- .64, p = .046, two tailed) but only marginally with the duration of the session; participants who made more errors showed a larger drop in AERs amplitude than those who made less errors. No clear relationship between changes in N1 latency and errors on the VR test was found. These findings do not seem to support the model of allocation of resources, e.g. the notion that brain resources to process irrelevant auditory stimuli were reduced during the VR task, but rather tend to suggest a buildup of mental fatigue after a prolonged exposure to a relatively stressful VE as the primary cause of AER changes. Preliminary analyses did not find significant relationships between AER amplitude changes and changes in total scores on the symptoms checklist, though trends were in the expected direction for symptoms related to mental fatigue. Alternative explanations are also possible and cannot be fully ruled out at this time. For example, a simple adaptation effect may have taken place. Also, the VE employed at post test may have captured subjects' attention differently than that used for the baseline period, though it seems unlikely after a long testing period. Overall, these findings appear to confirm our previous reports (Pugnetti et al., 1996) that the irrelevant probe technique can be used to track subjects' mental state, though a precise definition of the factors involved will need additional analyses.

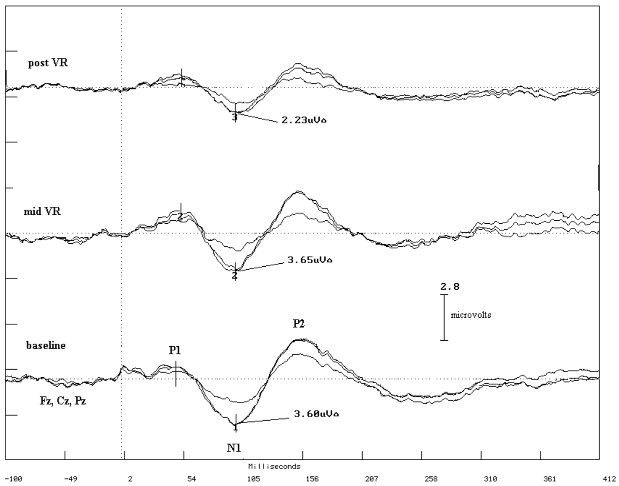

Figure 1. *Group averaged evoked responses to auditory irrelevant probes. Superimposed averages from Fz, Cz and Pz electrodes relative to the baseline, mid test, and post test periods; negativity is plotted down.*

Table 1. *Effect of VR testing on AER group measures*

Group measures	**Before VR test**	**After VR test**	**paired t (df 9)**
P1-N1 amplitude (uV.)	4.28 ± 1.84	3.26 ± 1.4	2.48 .03
N1-P2 amplitude (uV.)	6.37 ± 3.33	3.90 ± 1.5	3.25 .01
P1 latency (msec.)	51.0 ± 8.40	58.7 ± 10.8	-2.38 .04
N1 latency (msec.)	95.2 ± 97.9	97.9 ± 3.5	-0.74 n.s.
P2 latency (msec.)	151.5 ± 11.0	152.3 ± 9.2	-0.18 n.s.

4.2 ERPs to task-relevant probes

Clearcut ERPs to negative feedbacks (a combination of visual and auditory stimuli to provide a relatively robust input) were retrieved from all the EEGs analysed so far. These potentials, also known as slow cortical potentials (SCP) or endogenous potentials, are known to originate mainly in cortical structures and in thalamic nuclei. They are generally produced in response to unpredictable or rare events, variations in background stimulation, and periods during which a reaction is anticipated (see Rockstroh et al., 1989, for a comprehensive description of ERPs). The best known is the P300-SW complex (Figure 2). The amplitude of the ERPs we recorded was considerably larger than that of the AERs, but tended to vary over time in individual cases. The effect of experimental variables on the pattern of these slower brainwaves, such as their predictability, changes in the difficulty of the task, in psychophysical stress, or discouragement cannot be defined with any certainty at the moment, and will be the subject of future reports. As subjects were required to press the joystick trigger as quickly as possible after getting the feedback, we were able to record reaction times to single trials and to collect EMGs and corresponding shifts in brain potentials levels. Individual reaction times varied between 300 and 600 msec. (mean 374 ± 130 msec.) after feedback onset.

EMG responses were slightly preceded by a negative shift in SCP following the earlier ERP complex described above, and coincided with a positive shift. Because of the complexity of the stimulation and the absence of a suitable preparatory delay between the feedback and the motor response, it is presently unclear whether the late positivity (LP) on central and parietal leads can be interpreted as a final component of the cortical motor response or as a delayed P300 emerging after the end of a large motor negativity (MP or motor potential). Both components were more evident on central (Cz) and parietal (Pz, P3 and P4) regions. At preliminary analyses, SCP amplitude measures did not correlate with number of errors, duration of the session, and with reaction times, but did correlate significantly with the amplitude of the P1-N1 component of the AERs. This is not surprising as the main stimuli had the same modality, and because both responses reflect psychological concepts (attention) to a greater extent than a single ERP component (Rockstroh et al., 1997). The SCP complex was preceded by a slight negativity arising about 300 msec. before the acoustic stimulus which is evident in the averaged tracings of figure 2. In individual cases this negativity was more pronounced and an alpha-blocking phenomenon was evident in high-alpha subjects (see 4.5). We interpret this component as an anticipatory negativity (AR), as the subjects quickly learned that a negative feedback could occur after the opening of the mid-hallway door. Another long-lasting negativity is also present after the P300 (or LP) component which we tentatively interpret as a pronounced slow wave (SW) typical of a P300-SW complex or as a sustained motor negativity (or a superposition of both) given that several subjects produced multiple trigger responses after the first one in an attempt to delay or reduce the fog.

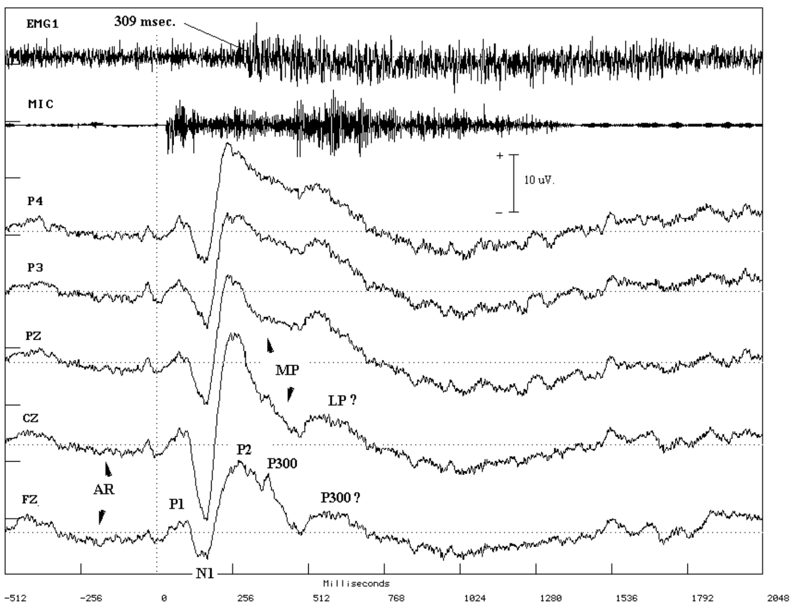

Figure 2. *Group averaged ERPs to negative feedback stimuli after a wrong door match.Positivity is plotted upwards. MIC refers to the auditory stimulus (gunshot); EMG1 refers to the surface electromyographic bipolar recording from the flexor digiti muscle of the dominant forearm which was activated to press the trigger of the joystick. Amplitude scale refers only to EP channels.*

4.3 ERPs to other significant events

Averaged ERPs could also be identified in response to events that are generally not produced in traditional laboratory studies and that may be more specific for interactive VR environments. As the subjects had to navigate a series of rooms, the opening of doors that led from a hallway to the next room or from a room to a hallway provided a suitable stimulus. During a VR session three such events occurred for each of the 32 rooms visited, for a total of 96 events. The first event occurred when subjects closed the entrance door by looking at it from the center of the room, the second when subjects opened the exit door on their way to the mid-hallway door (in the case of a wrong match) or the door leading to the next room (correct choice), and the third when they entered a new room. The first event was necessary to let the exit doors appear, whereas the other two were necessary to have access to the following environments. The first event had a stronger conditional meaning compared to the other two and was the result of more demanding manouvres in the VE. A positive-going potential peaking about 500 msec. before full closure of the entrance door (event 1) was recorded. The ERP seemed to involve to a greater extent posterior regions of the brain, as it was larger on CZ and parietal leads (Figure 3). The relative spread of the averaged waveforms may be explained by a jitter of individual response latencies caused by the fact that the triggering event was not a sharp one, but took some time (about 1 sec.) to develop. No reliable and genuine (e.g. non artifactual) brain responses were produced as subjects entered a new room and when they opened the exit door. We have already described brain responses preceeding and following the opening of the mid-hallway door (see 4.2). The ERPs to event 1 may then be associated to the appraisal of the outcome of the positioning manouvres necessary to move to the center of the room and turn backwards to face at right angle the entrance door and let it close. This manouvre can be extremely difficult in conditions of low visibility, as described in Meehan et al. (this volume).

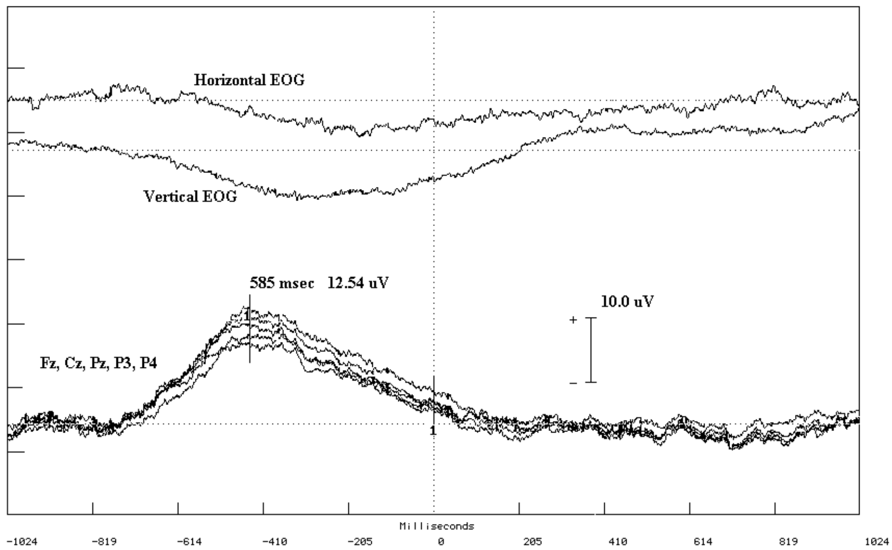

Figure 3. *Group averaged ERPs to event 1 as described in the text. Door closure was complete at time 0. Positive peak at 585 msec. from onset of event is larger at posterior recording sites.*

4.4 Short-lived rhythmic EEG changes

Phasic spectral changes in ongoing EEG were also considered as indices of moment-to moment variation in brain arousal levels. It was hypothesized that such changes could occur as a result of the momentary cognitive demands specified by being in a given virtual environment. Alpha (8 to 12 Hz) EEG power over posterior scalp regions was preferred to other spectral variables because of the lower sensitivity of this measure to more anterior sources of artifacts in behaving individuals. Though high amplitude alpha waves are generally suppressed in individuals performing visual tasks, transient increases in these rhythms occur that index brief periods of relative rest in external input processing. We sought to detect whether changes of EEG alpha waves were detectable after the occurrence of significant events. Mean EEG power in the 8 to 12 Hz band was significantly increased over parietal, but sometimes also over more anterior leads, during the 4 seconds following selection of the exit door (event 2 as described before) as compared to the 4 sec preceeding this event. No significant changes appeared to be associated to the other two events. Because alpha waves are known to be associated with idling, we interpret these findings as indicating that the brain was taking short breaks between periods of active processing, such as those occupied to make an important choice. This general interpretation is supported by the finding that the fog (= lower visibility) suppressed the post-event alpha increase (a stress response?) in those who made many errors (see 4.5).

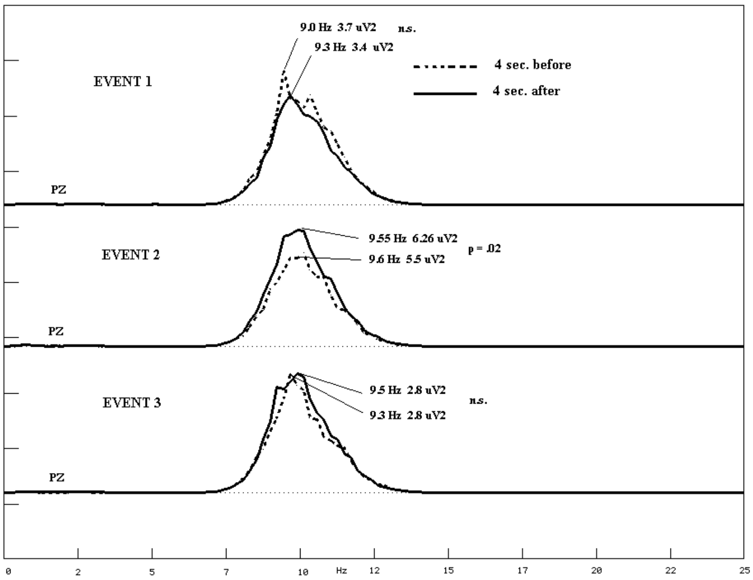

Figure 4. *Group averaged alpha (8-12 Hz) power of 4 sec. epochs taken from the Pz electrode before and after events 1 to 3 as described in the text. Y scaling differs between the three pairs of spectra.*

4.5 *Long-lasting EEG changes*

More durable increases or suppressions of EEG rhythms are being studied in connection to changes in testing conditions and subjects' state. Because the latter were dependent on individual characteristics, adaptation to the experimental setup and to performance, results are not described in terms of group findings. Again, measures of alpha power changes were preferred for these analyses. High alpha subjects provide more reliable results as they produce rather sustained rhythmic EEG activity also during active mental processing with eyes open. There were 5 subjects whose mean alpha power in the 8 to 12 frequency range during the test exceeded 3.5 uV^2 (at peak frequency). Two subjects (males) made many errors and their task got very difficult from midtest to the end because of the fog. Three subjects (all females) did very well and did not get any fog during the test. Both bad performers showed a sharp decrease in mean alpha power when fog became incapacitating; one example is shown in Fig. 5B. Of the good peformers, two showed a progressive increase in mean apha power as the number of correct choices increased (Fig. 5A), whereas one did not show any significant change until the end of the test. These findings can be interpreted as further proof that the spectral content of ongoing EEG can be used to monitor dynamic aspects of adaptation to the task and of task learning.

4.6 Other results

All the 10 participants were able to terminate the VR sessions. Total scores on the symptoms checklist showed a moderate mean increase after the session (2.8 ± 1.9 vs. 4.2 ± 4.0 Wilcoxon Z –1.3 , p = .18, 2-tailed). Only 1 subject complained of mild nausea toward the end of the VR session, but agreed to terminate her test; her data were not included in the present analysis. Two subjects reported dyscomfort - one mild and the other annoying - caused by the leads and sensors attached to their skin. They were both able to concentrate on the task and did it well. One further subject reported difficulties handling the joystick.

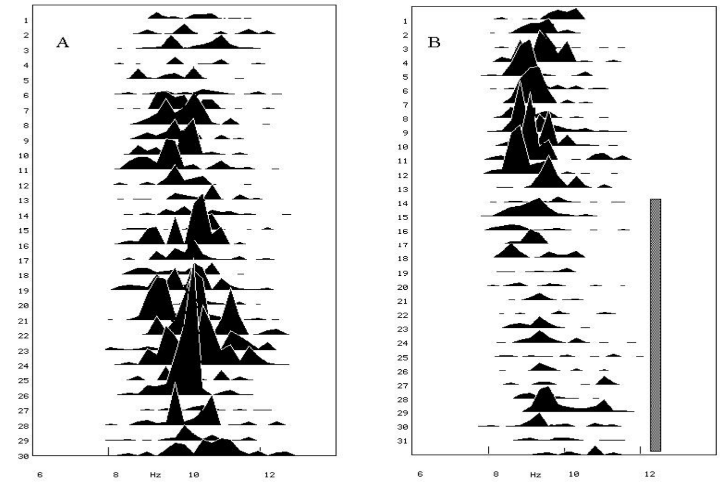

Figure 5. *Compressed spectral arrays showing patterns of long lasting changes in EEG alpha (8-12 Hz) power during the VR test. In A (left) a good performer increased her alpha as she overlearned the task. In B (right) a poor performer suppressed his alpha as the task became more and more difficult; vertical bar indicates decreased visibility. Number of successive virtual rooms shown on ordinate.*

5. DISCUSSION AND CONCLUSIONS

This study confirmed that monitoring of electrophysiological brain activity of healthy individuals engaged in VR testing is technically feasible without affecting too much their ability to perform. A successful recording of ERPs from behaving individuals exposed to VR has also been recently reported by Bayliss (Bayliss and Ballard, 2000) and by Mager in Basel (Mager, 2000). The range of data obtainable by a careful segmentation of continuous polygraphic tracings is certainly wider than that described in this and in others' reports. Also, inspection of individual records and videos can provide further insight into the rich phenomenology of brain-behaviour correlations during exposure to virtual reality which, however, is difficult to summarize. We believe that relatively simple techniques such as EEG spectral analysis and response averaging are sufficient to provide significant amounts of information, not otherwise obtainable, which can be used to better understand the way our subjects react and adapt to VR. More specifically, we have been able to document both short-term and long-term brainwave changes induced by the participation to our experiment, some of which may have been easily anticipated based on established psychophysiological knowledge (see also Meehan et al., this issue), and others that would have not been easily foreseen and which will require further study to be fully understood. To summarize, event-related potentials and EEG analysis provide useful means to objectively assess - in combination with behavioral observation and rating scales – important issues such as mental fatigue, overall dynamics of learning, orienting reactions to sudden sharp stimulation, anticipation of meaningful events, appraisal of outcome of actions performed to achieve a goal, impact of changes in task difficulty. Though this approach may not appear to have a immediate relevance to VR applications for the disables, we think that it has relevance for those who must create such applications and to those who must decide how to propose them to disabled users. Without implying any simplistic approach to complicated issues, we just mention a few questions which may be addressed using psychophysiological methods: how long a given VR task should last to achieve an optimal effect (e.g. learning) without stressing inadequately (in either direction) physiological resources? How much the strenghth of a feedback should vary to maintain an optimal attention to it? When a given event or a consequence of an action become predictable? What is impact of distracting events (either wanted or not) on the processing of the main stimuli? When does a significant mental fatigue really occur? How do we know a subject's attention is really captured on a moment-to-moment basis? What is the impact of mild physical distress induced by the VR setup on our subjects' processing capacities? Is a given brain signal reliable enough to be used to drive specific aspects of the VE, to optimize performance, or to achieve control of assistive devices in simulated situations?

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Embodying cognition: a proposal for visualising mental representations in virtual environments

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ABSTRACT

This paper examines the possibility of visualising the most abstract knowledge in virtual environments: mental representations that are involved in the basic cognitive processes. Metaphorisation is a key tool for creating virtual environments capable of embodying what is in the mind. The aim of these environments is to improve the learning and rehabilitation of users with cognitive disabilities. We propose to design symbolic environments in which concepts are converted into a bodily experience by means of the metaphorical projection from the abstract to the physical domain. Our proposal is illustrated by the description of a case study: the representation of categories in a virtual environment for blind children.

1. VISUALISATION OF COGNITION: A NEW CHALLENGE FOR VIRTUAL REALITY

Ever since it appeared on the scene, the aim of virtual reality technology has been to build synthetic worlds capable of simulating, representing or recreating the different facets and sides of reality. The virtual environments developed so far can be classed according to the sort of visualisation they provide. In this paper, we use the term "visualisation" in the broadest sense as a multi-sensory experience in an artificial environment. Although immersive virtual reality systems theoretically can provide different sorts of perception (visual, haptic, auditory, kinaesthetic), vision is usually the most important or only type implemented. So, as employed here, the term "visualisation" represents all the senses, that is, the possibility of touching, picking up and handling objects, listening to sounds or moving around in a virtual environment rather than just the ability to see.

In the following classification we propose below, virtual environments are divided into three major groups according to the type of objects and contents they can visualise:

(a) Visualisation of things, objects, activities, scenarios or persons in virtual environments aiming at imitating reality; for example, buildings or architectural spaces for virtual walkthroughs, flight simulators, systems of telepresence for long-distance face-to-face communications, etc.

Significant examples of this type of environments are Street World and Object World, two applications developed by the University of North Carolina for autistic children. The first simulates an urban scenario: a street lined with buildings and a pavement, a car and a stop sign. The child can safely walk along this virtual street and learn how to cope with a range of different situations. The second scenario, Object World, serves to stimulate learning in a classroom containing objects that can be identified by their shape, colour or the use to which they are put and which the student can handle directly (Youngblut, 1998).

(b) Visualisation of information: text and documents, data and information bases, including hierarchies, networks, frameworks and systems; for example, virtual environments as information spaces, in which users can explore, retrieve, organise and browse a collection of references to information sources located on the Web or elsewhere.

A possible example of a system belonging to this group is proposed by researchers from the Argentine University of La Plata and the University of Chile: a framework for adapting graphical hypermedia interfaces for blind users (Lumbreras et al., 1996). Using this framework, they have been able to develop a hypermedia system with 3D sound that can be used without the need for any visual information.

(c) Visualisation of knowledge is concerned with exploring information in such a way as to gain an understanding and insight into the data. This is a fundamental goal of much scientific research. It can be used to understand and solve scientific problems, look for regularities or connections, find hidden patterns in data and create new models. Scientific visualisation in virtual environments is the art of making the unseen visible: torsion forces inside a body, heat conduction, flows, plasmas, earthquake mechanisms, botanical structures or complex molecular models.

A representative project is VESL (Virtual Environment Science Laboratory). Its ultimate goal is to build a virtual sciences laboratory that can be used by any student, including users with cerebral palsy or other motor disabilities by means of different mechanisms and interfaces, including verbal orders (Nemire, 1995). Students can use the current prototype to explore the world of atoms and learn concepts and laws from atomic physics.

Our work aims to go one step further: to design and develop virtual environments that provide visualisation of cognition. Visualisation of cognition means the externalisation of mental representations embodied in virtual worlds. We are interested in how to map mental contents into sensorial representations and experiences in a virtual environment. Mental representations are the internal system of information used in cognitive activities (perception, language, reasoning, problem solving, etc.). Cognitive processes are essential in any activity demanding intelligence: recognising a voice, understanding a poem, learning a new concept, remembering a route, putting an object into a set or category, etc. All these activities involve people applying certain operations to mental content. We have to represent the things that the mental content is about in our minds. Different disciplines, like cognitive psychology, philosophy (logic, epistemology), cognitive science or artificial intelligence, are concerned with how things and processes outside minds can be represented inside minds (so that they can be dealt with by brains or machines).

These representations cannot be observed directly. However, we believe that their embodiment in virtual environments could help users with cognitive disabilities (learning or linguistic problems) to experience them through the senses and thus to understand them better. Such environments could be fully explored, allowing users to (re)build their own cognitive model and enhance learning by means of the sensory interaction with the virtual model.

The first problem that arises is how to transfer a mental representation –which is invisible to the senses, abstract, devoid of physical profiles- to a virtual environment based mainly on sensory perception. Is it possible to visualise mental contents in a virtual reality system?

2. THE ROLE OF METAPHOR IN VIRTUAL ENVIRONMENTS

Metaphor is much more than just a linguistic medium, it is also a mechanism of thought, an instrument capable of conveying new cognitive contents (Radman, 1997). Metaphors are a guide to the discovery of invisible things and abstract notions. If we want to learn or discover something new, we have to be able to imagine it first. Thanks to metaphorisation, it is possible to gain new knowledge. The analogies or similarities established by metaphors generally follow the same pattern: the use of the known, the familiar and the concrete to express the new, the unknown and the complex. Metaphor is usually employed in scientific research to structure and understand a new domain in terms of a known field. For example, Niels Bohr used visual metaphor to describe atomic processes in 1913: the atom behaves as if it were a minuscule solar system

Metaphor is also a key element in the design, construction and use of virtual environments. Firstly, the user interface of any virtual environment calls for the design and elaboration of metaphors that symbolise the different forms of navigation and interaction with the artificial world. On the other hand, if the end users of a virtual environment have any sort of sensory disability (like blindness or deafness), the creation of kinaesthetic metaphors that ease perceptual transposition is a must. For example, a virtual environment for blind users would require metaphors capable of representing the visual information and converting it into tactile or auditory information. Besides, metaphorisation is essential for representing the concepts or contents furthest removed from material reality: as the complexity of the type of visualisation becomes more complex and abstract in the virtual environment (objects-information-knowledge-mental representation), metaphor plays a more significant and central role.

We have claimed the metaphorical design of virtual environments for education elsewhere (Sánchez et al., 2000). The main component of our design is what is termed metaphorical projection. The metaphorical projection can be viewed as a mapping between the source knowledge of the real world (what is to be taught) and the virtual environment (what is to be designed). The purpose of this transfer is to develop a network of metaphors that define both the structure of and the forms of learning, navigating and interacting with the virtual world, that is, the metaphorical projection acts on four interdependent planes: the structural plane, the learning plane, the navigation plane and the interaction plane. The most important is the structural plane, whose metaphors establish the architectural principles of the virtual scenario, which will determine its ultimate form and structure. The goal is to create an isomorphism or structural correspondence with a domain with which students are already familiar, thereby easing understanding and learning of didactic contents. The learning plane metaphors are used to design the educational strategies (the activities to be performed by the student in the virtual environment, the role of the teacher, etc.). The navigation and interaction planes are composed of the metaphors that define how users can move about in and interact with the virtual environment. These four planes of metaphorical projection form a systematic set of metaphors, which provide the guidelines for designing and building the entire virtual world.

In our opinion, only through metaphor is it possible for users of a virtual environment to visualise and physically experience the abstract. The imperceptible, the mental, the complex thus becomes accessible to users, something that they can understand and interpret. We, therefore, propose to address the design and construction of metaphorical virtual environments specifically directed at users with some sort of cognitive impairment or retardation. These artificial worlds would embody the mental representations and models mainly to strengthen user rehabilitation or learning. In the next section, we will briefly examine a case that will serve as an example of our proposal: a virtual environment directed at blind children for stimulating and improving their ability to classify.

3. REPRESENTATION OF CATEGORIES IN A VIRTUAL ENVIRONMENT FOR BLIND CHILDREN: A CASE STUDY

There is nothing as essential as categorisation for human perception, thought, action and language (Lakoff, 1987). Every time we see something (as a class of thing), every time we reason (about classes of things: countries, diseases, emotions, etc.) or intentionally take any action or talk about anything, we are employing categories. Categorisation is central to our cognitive abilities. It is vital for us to have an understanding of how we categorise to be able to comprehend how we think and work as human beings. We have categories for everything that can be thought about and perceived: categories of biological species, physical substances, artefacts, colours, emotions, words, etc. Category learning is the most general form of cognition.

3.1 Main Concepts of Categorisation

Some basic concepts of categorisation, taken from the classic work of Eleanor Rosch (1978), will be used throughout this section. These are taxonomy, basic level, attribute and prototype.

Taxonomies are systems in which the categories are interrelated by relationships of inclusion. A conceptual hierarchy (e.g., *animal – bird – sparrow*) has different levels of generality or abstraction, depending on category inclusiveness.

A taxonomy is divided into three levels or category types: generic or supra-ordinate categories, specific or subordinate categories and basic categories. This basic level always comes between the more general and more specific category, at an intermediate level of inclusiveness. For example, if *table* and *bird* are basic categories, the supra-ordinate categories are *furniture* and *animal* and the subordinate categories *kitchen table* and *sparrow*.

A category can also be considered as a series of traits or attributes that are shared by most of the members of the category in question. For example, the category *chair* would be composed of attributes like *seat, legs, back*, etc. Prototypes are the specimens with a definite air of family within a category. So, the prototype acts as the category reference point.

3.2 Categorisation by Blind Children

Generally, blindness complicates the process of categorisation, as visual perception is one of the main sources for acquiring knowledge about the world. But, exactly how is category learning affected in blind children? According to Peraita et al. (1992), blind children face two basic problems for categorisation:

Firstly, a deficit in the generalisation and structuring of categories. Sight impairment prevents blind children from inducing or abstracting the most important characteristics of a class to form a general representation. Generic classes do not have an concrete referent, hence their difficulty. The process of generalisation calls for experience with many concrete specimens. Young children have little knowledge of supra-ordinate and subordinate classes or of taxonomic organisation, whereas the basic level is the most significant and best characterised.

Secondly, an alteration or delay in language learning. A distinction has to be made between the lexical level (lexical label) and the conceptual level (the mental representation) in a child's (blind or otherwise) process of language learning. The child must learn to establish the right connections between these two levels. Development of the referential function is a necessary condition for the process of naming and conceptualising reality. When the absence of visual information interferes with the process of identifying the referents of words (lexis), the "mental lexicon" may also be disturbed.

Language learning is delayed, especially in the early childhood of the blind, because they have no visual stimulation. "Verbalism", the use of meaningless words and expressions that have no particular sensory referent, is a common phenomenon; that is, blind children tend to learn and use some lexical labels without an associated mental representation.

3.3 Acquisition and Representation of Categories according to Lakoff: an Experientalist View

Lakoff's main thesis (1987) is that we organise our knowledge by means of structures called idealised cognitive models or ICMs. Each ICM is a complex structured whole, a gestalt. The structure of thought is characterised by cognitive models and the categories of the mind correspond to elements of these models.

Cognitive models derive their fundamental meaningfulness directly from their ability to match up with pre-conceptual structure. Some experiences are structured pre-conceptually because of the way the world is and the way we are. At least two forms of pre-conceptual structure exist:

(a) Basic-level structure: Basic-level categories are defined by the convergence of our gestalt perception, our capacity for bodily movement and our ability to form mental images. Water, wood, stone, dog, cat, chair, table... are basic-level concepts, that is, directly meaningful concepts. (Note on imagery in blind people: some papers, e.g. De Beni and Cornoldi (1988), show that impaired vision does not eradicate mental images. The blind can form images that possess many of the essential characteristics of objects, like texture, shape and others that are not based on visual perception).

(b) Kinaesthetic image-structure: Image schemas are simple structures that constantly recur in our everyday bodily experience (containers, paths, links, forces, balances) and in various orientations and relations (up-down, front-back, part-whole, centre-periphery, etc.). The consideration of certain patterns in our experience (our vertical orientation, the nature of our bodies as containers and as wholes with parts, our ability to sense hot and cold, etc.) suggests that our experience is structured kinaesthetically in a variety of experiential domains.

These two structures are directly meaningful, because they are directly experienced owing to the nature of the body and its mode of functioning in our environment. Given basic-level and image-schematic concepts, it is possible to build up complex cognitive models. Image schemas provide the structures used in those models. Some schemas (like container, link, part-whole, centre-periphery, up-down, front-back...) can structure our experience of space. Lakoff claims that the same schemas structure concepts themselves. When we understand something as having an abstract structure, we understand that structure in terms of image schemas. According to the spatialisation of form hypothesis (Lakoff, 1987):

- Categories are understood in terms of container schemas
- Hierarchical structure is understood in terms of part-whole schemas and up-down schemas
- Relational structure is understood in terms of link schemas.

The spatialisation of form hypothesis requires a mapping from physical space into a "conceptual space". Thus, spatial structure is mapped into conceptual structure. Specifically, image schemas (which structure space) are mapped into the corresponding abstract configurations (which structure concepts). The spatialisation of form hypothesis thus maintains that conceptual structure is understood in terms of image schemas, plus a metaphorical mapping.

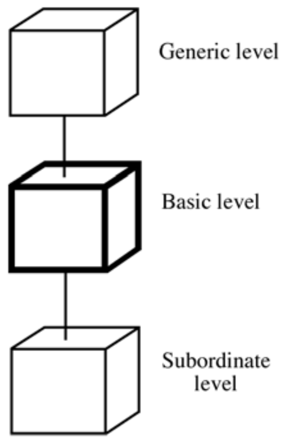

Figure 1. *Cube network*

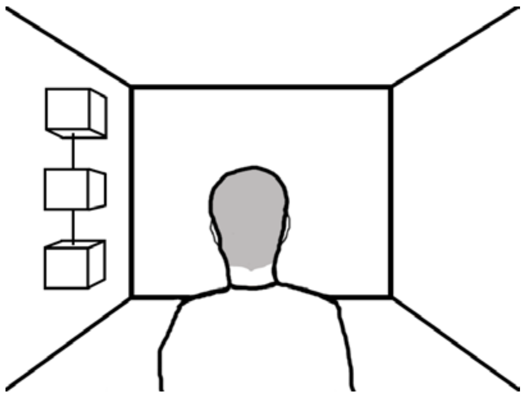

Figure 2. *Room-container*

3.4 Preliminary Design of a Virtual Environment for Blind Children

In this section, we present a preliminary design of a virtual environment that will serve as an example of category representation. Preliminary design means a simplified (and, therefore, incomplete) and idealised (not taking into account implementation difficulties) design.

Its potential users are blind children with categorisation and linguistic labelling problems. The content is focused on a three-element taxonomic hierarchy: *furniture – chair – fold-up chair*. We will follow Lakoff's theory for the representation of this taxonomic hierarchy, according to which each taxonomy is an idealised cognitive model, a hierarchical structure of categories, in which each category is structurally represented by a container schema and the complete hierarchy by part-whole and up-down schemas.

The virtual environment must be designed in accordance with natural metaphors, that is, motivated by the structure of bodily experience (for Lakoff, human categorisation is partly based on the nature of human bodies). The metaphorical projection guiding the design of the virtual environment is carried out on four different planes: the structural plane, the learning plane, the navigation plane and the interaction plane.

(a) Structural plane. The goal is to convert the conceptual space (the hierarchy) into a physical space, establishing a structural correspondence between Lakoff's schemas and a similar virtual scenario. We propose to design two virtual environments. The first will represent the conceptual hierarchy and the second, each category.

- Cube network. The hierarchy is represented as a network of cubes ordered vertically at three spatial levels (see Figure 1). Each cube-container represents a category of our example: *furniture* (generic level), *chair* (basic level) and *fold-up chair* (subordinate level). The full network symbolises the taxonomy. The scale or size of this environment must be very small so that the child can explore the cube network using its hands (equipped with data-gloves or a similar device).

- Room-container. Each category is symbolised by a 3D scenario, a life-size cube-shaped room (see Figure 2). Two items are arranged inside the room. Firstly, the above-mentioned cube network is located at one side of the scenario and within the user's reach. This network acts as a map or guide, letting the child know what room it is in (the cube in use can be marked by means of a distinctive tactile or auditory characteristic: shape or size, texture, sound or verbal message). Secondly, there is one or more objects representing the category, which can be handled and explored by the user, in the centre of the room.

The creation of two virtual environments, the network and the room-container (which is really only one spatial scenario: the room, that always contains the cube network) is justified because human categorisation is understood as a two-fold process. On the one hand, categorisation answers to the identification of perceptual and functional attributes by sensory interaction (by means of which specimens of each category can be identified and distinguished). On the other hand, categorisation is also based on theoretical or mental constructs of the subject (by means of which to generalise, induce and classify elements in a conceptual hierarchy).

(b) Learning plane. The selection of activities that will guide the child's learning in the virtual environment can depend on many factors (age, pupil's background knowledge, type of impairment concerning categorisation, etc.), but the following are advanced as a suggestion. Each level, each room-container, could call for different sorts of activities or exercises:

- Basic level (room containing chair). This should be the starting point, the first room visited by the child. Remember that basic categories are especially important, as they are the first categorisations made by the child (have similar external forms and develop similar motor programs). This room would contain a virtual chair, which would represent all the chairs of the basic category. This would be a prototype chair, with all its definitional components: seat, back and four legs. The activities of this level would be committed to understanding the component "parts of" or "part-whole" of the basic concept (linguistically expressed by expressions like "*has*...", "*its parts are*..."). The virtual chair could be explored and handled in ways that are out of the question in a real environment: the child could take apart and reassemble the chair, each component could speak and identify itself when the child touches it ("*hello, I am a seat*") or give additional information ("*I am shaped like*...", "*I am made of*..."), the (animated) chair could fall over or be positioned differently for the child to stand it up correctly, etc.
- Subordinate level (room containing fold-up chair). As soon as the child is familiar with the basic category chair, it is ready to learn about different types of chairs (in this case, the subordinate category fold-up chair). The activities at this level are focused on learning to distinguish the evaluative or rateable component (linguistically expressed by expressions like "*is used to*...", "*is* + adjective", "*is used as*...") and on understanding what similarities and differences it has with the prototype chair of the basic level by directly interacting with a virtual fold-up chair (or several different types of fold-up chair).
- Generic level (room containing furniture). This level would aim to stimulate the process of generalisation and abstraction (e.g. "*a chair is a piece of furniture*"). The room could reproduce a real setting, like a dining room (or a kitchen or lounge) with different sorts of furniture, like chairs, a table, a cupboard, shelves. By exploring the virtual scenario, the child would be able to get to know different specimens of furniture, know how they are arranged in a given setting and learn how to recognise the common characteristics of all the pieces of furniture.

(c) Interaction and navigation planes. The child would not need to move to go from one room to another or to reach objects. Either a verbal order or a given hand movement or manual indication on the cube map would suffice to move up or down a level. All it would take is a spoken instruction or a predetermined gesture to reach objects, and the things would move in front of the child or be placed directly into its hands. The objects could feature magical properties useful for supporting learning: they could break up into parts, talk, move, change size or shape, etc. A teacher or instructor-guide could accompany the child, especially during its first visits to the virtual environment.

A virtual environment like this one is beneficial in many ways: the blind child can broaden its experience and enter into contact with many elements of a class (thus making it easier to generalise). The virtual environment promotes activity based on gestures and manipulation and allows the child to experiment directly with objects, while establishing the respective linguistic expressions (which are associated with their referents). All this takes place in a safe environment that is completely harmless for the child.

The example of the environment described above is very simple but could be extended in several ways: enlarging the taxonomy by including more elements at each level; changing the conceptual domain (animals, vehicles, plants...) without modifying its structure; creating a visual or graphical version of the environment for children with remaining sight or sighted users with other categorisation-related cognitive problems (aphasia, mental retardation, autism), etc.

4. CONCLUSIONS

As shown in our case study, embodiment in virtual environments provides a link between cognition and experience (abstract concepts are based on bodily experience). The cognitive models and concepts that represent the taxonomies are embodied in a virtual environment that reproduces the same patterns and schemas that we use in everyday categorisation: categories as containers and hierarchies as spatial structures.

Much of our technology, -telescopes, microscopes, photography, television-, has provided ways of extending basic level perception in the visual domain. Virtual reality technology has two other benefits: firstly, it extends perception to other sensory domains (tactile, acoustic, movement) and, secondly, it is capable of creating semantic spaces, where the abstract can be represented metaphorically in a physical scenario. By building virtual environments, we can actually create perceptual worlds that embody mental models created entirely in the mind. These artificial environments can externalise and represent the inner landscape of our mind, thus enhancing the learning process. We believe that virtual reality can make a great contribution to the study of the ideas, concepts, theories and methods developed by cognitive science and pedagogy. In the near future, virtual environments are likely to become an indispensable tool for these sciences and the main results could be applied to the rehabilitation of some cognitive disabilities.

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Cognitive intervention through virtual environments among deaf and hard-of-hearing children

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ABSTRACT

The deficiencies of the auditory sense in the hearing-impaired raises the question as to the extent to which this deficiency affects their cognitive and intellectual skills. Researchers have found, that in regard with reasoning, particularly when the process of induction is required, hearing-impaired children usually have difficulties (Hilleyeist & Epstein, 1991). Another cognitive process, which hearing-impaired children have difficulties in, is the ability to think in a flexible way. Studies have proven that hearing-impaired children tend to be more concrete and rigid in their thought processes. They usually choose one familiar means of solving problems and use it to deal with most of the problems that they encounter (King & Quigley, 1985; Laughton, 1988; Saraev & Koslov, 1993).

In recent years, one can identify a trend for active intervention in the cognitive capabilities of deaf children in a growing effort to improve their intellectual functioning (Gruler & Richard, 1990; Huberty & Koller, 1984; Martin, 1991). The uniqueness of this study is the use it makes of Virtual Reality, as a tool for improving structural inductive processes and the flexible thinking with hearing-impaired children. The results clearly indicate that practicing with VR 3D spatial rotations significantly improved inductive thinking and flexible thinking.

1. INTRODUCTION

Intelligent performance has two main expressions: a) thinking, which means making different activities over memory knowledge, and b) learning, which is the extension of this knowledge (Tzelgov & Nevo, 1996). "Thinking", as a concept, has many definitions and models. One of them defines thinking as a mental undermining process, which is directed to forming data system according to conscious goal, and right or wrong criterion (Glanz, 1989). "Thinking" is a broad field, and include many processes. This study dealt with *inductive processes* among hearing-impaired children. Trochim (1996) defined the inductive method as "bottom up"—i.e., a process which goes through the stages of making specific observations, creating testable hypotheses that lead to generalization and create generalized conclusions. Glanz (1989) reports on "induction of laws"—a process in which induces leads to the inference of common rules that dictate the order of components within a given system. It is possible to identify the rule by formulating it verbally by adding components to the system continuously or both—formulating and adding components.

Researchers (Hilleyeist & Epstein, 1991) have found that reaching a reasoned conclusion is a process in which hearing-impaired children have some difficulties. Although it may seem that hearing-impaired people are similar to normal hearing people in the structure of their thoughts and in their cognitive capabilities, auditory and language deficiencies may lead to lower verbal functioning and an overall lack of appropriate experience. The consequences, it is suggested, can be lower results in Conclusive Thinking and in reaching reasoned conclusions using inductive processing (Friedman, 1985; Hilleyeist & Epstein, 1991).

The goal of this study was to examine the influence of an intervention program, practicing spatial rotation in a Virtual Environment (VE), on the structure-inductive thinking among hearing-impaired children.

Another aspect, which the study focused on, was *Flexible Thinking*. Sternberg & Powell (1983) define flexible thinking as the ability to look at things from different angles. They point out that during adolescence the ability of the child to think flexibly is more prominent. This flexibility is expressed in two opposite directions. On the one hand, children exhibit better ability to think consistently and adhere to methods that proved effective in solving problems. On the other hand, when necessary, they are capable of changing their work methods and exchanging them for more successful methods. Flexible thinking is one of the most important characteristics of intelligent behavior.

Guilford (1967, 1970) claims that flexible thinking is the ability to create a flow of ideas while changing direction or correcting information. In his opinion, there are two types of flexibility

1. spontaneous flexibility—spontaneous change in the thinking process and the transition to another, and
2. adaptive flexibility—the ability to adapt to changing instructions. The component of flexibility appears to Guilford to be related to the ability to generalize and abstract.

Researchers studied the ability of hearing-impaired children to think flexibly both verbally and in terms of shapes. This study relates solely to non-verbal ability. Saraev & Koslov (1993) examined 100 deaf children and 164 hearing children between the ages of 7–12. One of their findings shows lesser ability in creative imagination among the deaf, and rigidity in their way of thinking. Also, King & Quigley (1985) claim that hearing children surpass deaf and hard-of-hearing children in creative ability. Laughton (1988) compared the traditional approach of teaching art to teaching programs geared to developing creative ability. He studied 28 deaf children between the ages of 8-10, who took part in one of the two programs for twelve weeks. The children were tested in the Torrance formal test before and after the intervention. It was found that there was a significant improvement in flexibility and originality among the children who studied according to the new program. Laughton (1988) also claims that by means of the appropriate teaching strategy it is possible to develop creative aptitudes with deaf children and to help them to become less concrete and rigid in their thinking.

In recent years, however, there have been growing efforts for intervening in the cognitive capabilities of the deaf children to improve their intellectual functioning. This trend is backed by the new assumption that deaf children have the same intellectual potential as normal hearing children. Researchers believe that they may fulfill this potential if the environment, the instructions and the available materials are adequate and motivate learning. Moreover, some researchers tend to emphasize the importance of intervention programs as a mean to improve the cognitive achievement of hearing-impaired children (Gruler & Richard, 1990; Huberty & Koller, 1984; Martin, 1991). The goal of such cognitive intervention programs is to assist the deaf child and promote certain thinking capabilities. Some of the intervention programs are using technology. Researchers report on the correlation between computerized activity and enhancing cognitive skills. They believe the computer has a hidden potential that can enhance the intellectual skill of the learner, develop self study strategies, enhance the ability to solve problems and develop thinking skills at all ages (Samaras, 1996). One can perceive the computer as a tool, which provides thinking and learning strategies. For example, Volterra, Pace, Pennacchi & Corazza (1995) examined the interaction of hearing-impaired children (aged 6-16) with the computer. They found that if deaf children were given learning context that allowed information with or without language through visual modeling, the children's motivation for learning would increase.

The purpose of this study was to examine whether it is possible to improve the induction process and the flexibility of thinking in hearing-impaired children with the help of a leading edge technology – *Virtual Reality (VR).*

Pantelidis (1995) defines Virtual Reality as an interactive multimedia environment, based on the computer, in which the user is assimilated into, and becomes an active participant in the virtual world. This technology can present information in a three-dimensional format in real time so that the user becomes an active participant in the environment that communicates interactively without the use of words. Virtual Reality makes it possible to convert abstract symbols to more concrete ones by providing a perspective on processes which is not possible in the real world (Darrow, 1995; Durlach & Mavor, 1995; Osberg, 1995; Pantelidis, 1995).

This study is unique since, as far as we are aware of, it is the first attempts to join the need of a cognitive intervention program for hearing-impaired children with Virtual Environment.

2. SUBJECTS

The participants in this study were 44 hearing-impaired children aged 8-11. The hearing loss in the better ear of the children ranged from 50 dB to 120 dB with mean loss of 88.62 dB (see table 1). They had no additional handicaps. The children came from integrated classes in two schools. In these schools the hearing-impaired children are taught primarily in small segregated classes, but also participate in general-school-activities. In some cases, some of the classes are taken with normal hearing children of their age. After taking into consideration the children's background data, the subjects were placed into one of two groups—the experimental group and the control group. The two groups were matched for age, gender, degree of hearing loss, cause of deafness and equivalent prior experience with computer (see table 1).

An additional group of 16 normal hearing children were selected in order to establish whether in general, hearing-impaired children achieve lower results than normal hearing children in inductive skills. The ages of the hearing children ranged between 8-10 (average age 8:8).

The sample of 60 children, therefore, comprised the following 3 groups:

- 21 hearing-impaired children who served as the experimental group.
- 23 hearing-impaired children who served as the control group.
- 16 hearing children who served as a second control group.

Table 1: *Mean Grade Level, Hearing Loss Level and Gender*

Group	N	Grade M SD	Hearing loss (dB) M SD	Gender Boys Girls
Experimental	21	3.00 .84	89.29 21.23	9 12
Control 1	23	3.60 1.35	87.95 18.30	12 11
Control 2	16	3.83 .83	---- ----	8 8
Total	60	3.42	88.62	29 31

3. PROCEDURE

Each subject in the experimental group was given 15 minutes once a week over a period of three months to play unguided a VR 3D Tetris game, involving the rotation of objects in space. Children in the hearing-impaired control group played with a regular non-virtual 2D Tetris game involving rotation for the same period of time. The subjects of the normal hearing control group were given no rotation tasks.

The experimental and control groups were evaluated before and after the experiment using two tests: Cattell and Cattell's (1965) sub-test of "Structural Sequences", and Torrance (1966) sub-test "Circles". This was done in order to establish whether practicing rotation exercises with VR has an effect on the structural inductive processing and on the flexible thinking of the subjects. Cattell and Cattell's (1965) sub-test of "Structural Sequences" has twelve items, each contains a series of three shapes that differ from each other according to a discernable pattern. The subject has to infer the pattern by induction and choose the missing fourth shape out of five possible choices. For each correct answer the subject receives 1 point. The range of possible scores is from 0 to 12. Cattell and Cattell (1965) report a reliability score of over 0.80 with groups of students. Torrance (1966) sub-test "Circles" was used in order to study whether practice in the rotation of three dimensional objects, which requires the ability to view objects from different angles, will have an impact on the flexibility of thinking with the subjects. The test includes verbal and non-verbal tasks. We used the non-verbal tasks owing to the verbal insufficiency of the subjects. The test includes 36 identical circles. The subject has to produce as many associations as s/he can to each stimulation. The subject accumulates points only if the circle is an integral part from the painting. The number of the different categories is equal to the amount of points that the subject receives. This test has been carried out many times over the years and has received the high score of 90 in reliability (Torrance, 1966).

Instructions to the tests were given orally in conjunction with sign language, to ensure that all children fully understood the requirements. The normal hearing subjects took the test once only.

4. VIRTUAL ENVIRONMENT

The VR hardware (fig.1) used in this research was a virtual reality interactive game, with software that is able to create a three-dimensional environment. The software (fig 2) included three games (Tetris, Puzzle and Center-Fill), in all of which the objective was to carry out certain demands via control over three-dimensional blocks. The subject had to fill a three dimensional block with various shapes made up of smaller blocks. The subject had to put the dropping blocks in the right place, and accordingly, accumulate points. In order to accumulate more points, the user had to act accurately and rapidly. The optimal solution was reached by a combination of selecting the most appropriate shapes and rotating them as required. The subject had to complete the blank locations on the "board" according to an induced rule which s/he had inferred, and fit the appropriate shape in the blank locations. Similarly, the control group # I practiced a similar routine using a Tetris style 2D game (not VR game).

Figure 1. *Virtual Boy- Nintendo.*

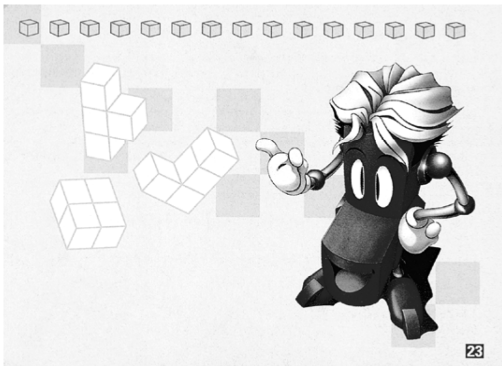

Figure 2. *Three-Dimension Rotation.*

5. RESULTS

The primary assumption of this study was that before practicing with spatial rotations, a distinct difference would be found between hearing impaired children and normal hearing children in their inductive thinking of spatial structure. After practicing in the VR mode, it was expected that the experimental group would improve to the point where no distinct difference would exist between them and the group of normal hearing children. That is to say, the scores of the hearing-impaired children in the experimental group will be similar to the grades of the normal hearing children. In order to test this hypothesis, a one-way analysis of variance was conducted for the Index of Structural Induction (ISI) in a before and after paradigm.

Table 2 exhibits the ISI scores for the three groups—the experimental group, the control group of the hearing-impaired, and finally, the control group of the normal hearing. In addition, table 2 exhibits the results of the variance's analysis. Figure 3 presents graphically the results before the intervention, and Figure 4 presents the results after the intervention.

Table 2: *ISI by Group and Time.*

Time		(1) **experimental HI**	(2) **control HI**	(3) **control hearing***	**F- scores**	**Contrasts significance**
Before	M	5.23	5.13	10.93	F(2,57)=62.48 P<0.001	P(1,2)=n.s. P(1,3)<0.001 P(2,3)<0.001
	SD	2.04	2.00	0.57		
	N	21	23	16		
After	M	11.00	5.65	10.93	F(2,57)=102.04 P<0.001	P(1,2)<0.001 P(1,3)=n.s. P(2,3)<0.001
	SD	0.77	2.08	0.57		
	T	-16.1	-2.02	-----		
	N	21	23	16		

HI= Hearing-Impaired.

The normal control-hearing group was tested only once. The results were entered for comparison with the "before" and "after" experimental results.

In observing the data in table 2 and figures 3 & 4, we can see that before practicing VR, no significant difference was found between the two groups of hearing impaired children (experimental and control). However, a significant difference in ISI was found between the hearing children and both the experimental and control groups of hearing impaired children. After intervention, however, there was no difference between the experimental group and the hearing children. Significant differences were found in structural inductive thinking between the two control groups (deaf and hearing) and between the experimental group and the two control groups (see table 2). After the intervention, the scores achieved by the experimental group of hearing-impaired children reached the same level as those of normally hearing children while the scores of the hearing-impaired control group remained low.

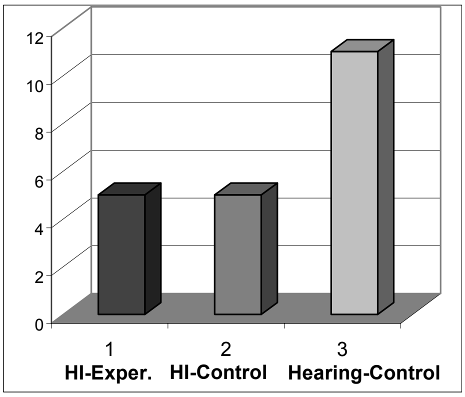

Figure 3. I*SI averages before intervention.*

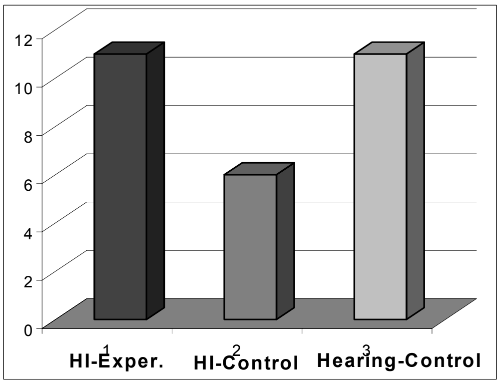

Figure 4. I*SI averages after intervention.*

The second hypothesis of this study was that a clear difference would be found between the experimental group of hearing-impaired children and the control group of hearing children in their ability to think flexibly before practicing spatial rotation, by means of the VR game. After the practice, in contrast, the ability to think flexibly improved in the experimental group to such an extent that no clear difference was found between this group and the control group of hearing children. That is to say, the scores of the deaf and hard of hearing children in the experimental group were similar to those of the hearing children in this examination. In order to verify this, we conducted a one-way analysis of variance.

Table 3 presents the averages in the measurement of the Index of Flexible Thinking (IFT) in the three research groups.

Table 3: *IFT by groups and by time*

Time		**HI experimental**	**HI control**	**Hearing control***	**Model P,F**	**Group P**
Before	Average	7.05	5.91	23.00	F(2,57)=177.92 P<0.001	P(1,2)=n.s. P(1,3)<0.001 P(2,3)<0.001
	SD	2.85	3.50	2.37		
	N	21	23	16		
After	Average	18.10	5.96	23.00	F(2,57)=102.04 P<0.001	P(1,2)<0.001 P(1,3)<0.001 P(2,3)<0.001
	SD	5.76	3.47	2.37		
	N	21	23	16		

HI= Hearing-Impaired.

Comment: the control group of hearing children took the tests once only; that is to say, the data in the table was copied from "before" to "after".

Figure 5 presents the average scores in IFT of the three research groups – experimental, control hearing impaired and control hearing, before intervention. Figure 6 presents the average scores in IFT after intervention.

A look at table 3 and figures 5 and 6 indicate that prior to the practice there was a considerable gap in flexibility of thinking between the research group of hearing-impaired children (both experimental and control groups) and the control group of hearing children. The difference favored the hearing children. No considerable difference was found between both research groups of hearing-impaired children (experimental and control groups). In contrast, after the practice, a clear difference was found between the experimental hearing-impaired group and the hearing-impaired control group in their ability to think flexibly, favoring the experimental group. A smaller but clear difference was found between the experimental group and the control group of hearing children; that is to say, the children in the experimental group improved their achievements significantly but did not reach the level of the hearing children in this index.

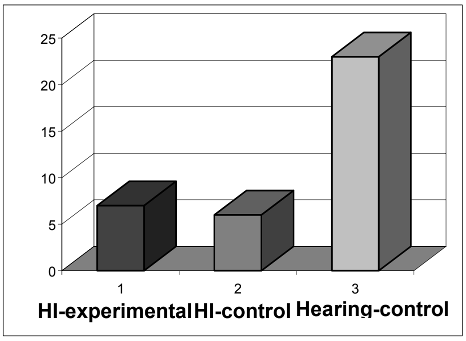

Figure 5. *IFT averages before intervention.*

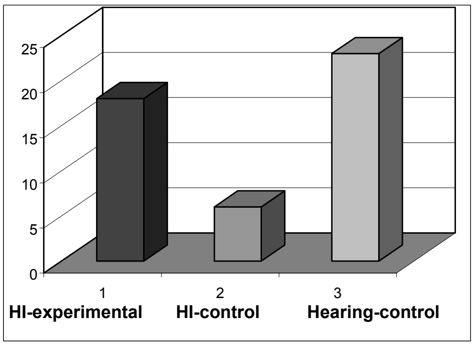

Figure 6. *IFT averages after the intervention.*

6. DISCUSSION

One of the objectives when educating hearing-impaired children is to stress with them the importance of nurturing independent thinking. One question to be asked is how can educators do so in a manner that will encourage and motivate the young children to be involved in an intervention program designed to improve their cognitive achievements.

Researchers have found that the functioning of the deaf improved following adequate learning, practicing and training (Gruler & Richard, 1990, Martin, 1991). Many of the current intervention programs do not exploit the vast possibilities available with today's technology, especially the innovative and attractive technology of VR. The uniqueness of this project is the use it makes of a virtual game that provides practice with spatial rotation, as a method for improving structural inductive processes and flexible of thinking with hearing-impaired children. As such, this has become one of the first attempts to use VR technology to improve the cognitive skills of deaf population.

The current research focused on two main fields- structural induction (ISI) and flexible thinking (IFT). The results of this study point to a distinct difference in structural induction's ability between hearing-impaired and normal hearing children before practicing, with the gap in favor of the normal hearing subjects. This finding reflects other studies that have similarly found that deaf and hard-of-hearing children have difficulties in the inductive processes and need assistance in this skill (Friedman, 1985; Hilleyeist & Epstein, 1991). The improvement of the structural inductive skills of the experimental group while exploiting a VR 3D game was such that no distinct difference remained between them and the normal hearing control group after the intervention. The hearing-impaired control group, however, who had no VR training, still maintained low scores. The gap between them and the normal hearing group remained the same even after the 2D practice.

The second research assumption was that hearing-impaired children tend to be rigid in their way of thinking, as compared to hearing children. This study found a clear difference in the ability to think flexibly between hearing-impaired children and hearing children before practicing, to the advantage of the hearing children. This finding is reinforced in previous studies which found that deaf and hard-of-hearing children possess lesser ability in creative imagination and have a tendency to rigidity in their thinking (Saraev & Koslov, 1993). After practice, the children in the experimental group improved in their ability to think flexibly with the help of the VR, and the gap between them and the hearing children narrowed. In contrast, the control group of hearing-impaired children continued to score poorly and the gap between them and the hearing children did not narrow. We can assume with caution that further practices might improve the results of the experimental group to the point where no noticeable difference will be between them and the group of the hearing children. This finding echoes that of Bunch (1987) who claimed that if hearing-impaired children are afforded opportunities to develop their potential and the teachers are provided with methods of encouraging creative thinking – deaf children will progress and will reach the level of hearing children.

These findings show a clear priority for the VR 3D intervention over a 2D "routine" one (not VR). We may assume that these findings occurred due to the differences between the two types of exercises. While, the children in both groups played the Tetris game for similar lengths of time, the only difference between them—the 3D virtual reality game vs. the 2D one—seems to have made all the difference.

A reasonable way to explain these results is through the essence of VR technology. VR technology creates a "pre-symbolic" communication in which the users can communicate with imaginary worlds with no use of words. This creates a world charged with sights, voices and feelings distinct from language and syntax

(Passig, 1996). The hearing-impaired children who used this technology were able to bring out their potential with no language or auditory limitations. VR does not limit the designer in the manner in which the information is presented, or limits his movements so the user of the technology is able to immerse within the learning environment (Pantelidis, 1995). This is how the deaf children where immersed in the game. They felt as if they themselves where moving the pieces, searching for the right ones, using inductive procedures and rotating them. This is to say that the abstract became less vague and more concrete. Different researches in the field of VR found that this immersion upgrades the interface with the senses and improves the understanding of abstract terms by converting them into more concrete ones (Darrow, 1995; Osberg, 1995).

One key attribute of VR is its interactivity—it allows the users to take a very active role. The increased liveliness and interactivity allows the user to become part of a virtual world. This tool is able to present information in 3D form and in real-time. It is an elaboration of a reality in which a person can hear, look, touch and bond with objects and images. This method allows the user to take an active role in the environment and not stay a passive bystander (Bricken & Byrne, 1992; Heim, 1992; Osberg, 1995; Powers & Darrow, 1994). Indeed, hearing-impaired children require a more active involvement in learning processes than normal hearing children do (Marzam, 1998).

Another way to explain the results is in terms of transfer strategies or tendencies from one field to another in order to explain a certain problem or phenomenon (Tishman & Perkins, 1996). The results of this study point that a transfer occurs from a rotation activity to a structural induction activity and to a flexible thinking activity. It seems possible to link rotation and induction or flexible thinking via mental imaging— rotation, induction skills and the ability to think flexibly requires the use of imaging (Piaget, 1971; Millar, 1989; Daniels, 1984). It is possible that due to this link between the variables a positive transfer occurred.

A different explanation of these results is simply that this tool is a fun and motivating one. Various studies have pointed out that children using VR enjoy using it and want to learn more by using it (Bricken & Byrne, 1992; Talkmitt, 1996). It seems that the high levels of motivation of the subjects resulted in their persistence with the program and their eventual success.

7. SUMMARY

In conclusion, the results indicate that the achievements of the hearing-impaired in the structural inductive processes and flexible-thinking ability, using a virtual environment, has improved. Beyond this contribution, which is important in itself, the biggest contribution of this research was the enhancement of the structural induction skill to the point where hearing-impaired children reached the levels of normal hearing ones. Another important contribution is the advancement of the ability to think in a flexible way to the point where hearing-impaired children almost reached the level of hearing children. It appears beneficial to do further work in this area.

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