

# *Proceedings of the 4th international conference on disability, virtual reality and associated technologies (ICDVRAT 2002)*

Book

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The 4<sup>th</sup> International Conference on  
Disability, Virtual Reality and  
Associated Technologies

# Proceedings

Edited by:

Paul Sharkey (Programme Chair)  
Cecília Sik Lányi (Conference Co-Chair)  
Penny Standen (Conference Co-Chair)

18 to 20 of September, 2002

Veszprém, Hungary

# ICDVRAT 2002

## Proceedings:

The papers appearing in this book comprise the proceedings of the 4<sup>th</sup> International Conference on Disability, Virtual Reality and Associated Technologies, held on the 18<sup>th</sup>, 19<sup>th</sup> and 20<sup>th</sup> of September, 2002 at the Villa Medici Hotel, Veszprém, Hungary. The papers presented reflect the authors' opinions and are published as presented and without change (formatting and minor editing excepted). Their inclusion in this publication does not necessarily constitute endorsement by the editors, by ICDVRAT, or by the University of Reading.

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# Introduction

The purpose of the 4<sup>th</sup> International Conference on Disability, Virtual Reality and Associated Technologies (ICDVRAT 2002) 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 across 10 countries, many of which show collaboration across international boundaries.

After a peer review process, the International Programme Committee selected 34 papers for presentation at the conference, collected into 10 plenary sessions: Virtual Environments for Assessment; Speech and Communication; Stroke Rehabilitation and Haptics I & II; Brain Injury and Rehabilitation; Enhancing Mobility; Communications and Interfacing to Virtual Environments; Training and Assessment; Acoustic Virtual Environments; and Virtual Environments for Special Needs. The conference will be held over three days at the Hotel Villa Medici, in the town of Veszprém, Hungary.

ICDVRAT 2002 follows on from the success of the first three conferences, held in Maidenhead, UK (1996), Skövde, Sweden (1998) and Alghero, Sardinia, Italy (2000). Abstracts from this conference and from the previous conferences are available online from the conference web site [www.cyber.reading.ac.uk/icdvrat/](http://www.cyber.reading.ac.uk/icdvrat/).

## 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 2002, 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 2004.

Paul Sharkey, Cecília Sik Lányi and Penny Standen

# Conference Sponsors

The sponsors of ICDVRAT 2002 are the University of Veszprém, Hungary and the Department of Cybernetics, of the University of Reading, UK.

Additional help in publicising the conference has been gratefully received from [vrpsych-1@usc.edu](mailto:vrpsych-1@usc.edu), [uk-vrsig@mailbase.ac.uk](mailto:uk-vrsig@mailbase.ac.uk), and Ability Magazine, amongst many others.

## Artwork

Artwork and Conference Layout by sckelp, adapted from original ideas of Eric Phipps and David Angus (ICDVRAT Logo) and from original clipart from the CorelDraw Clipart Library (ICDVRAT 2002 Graphic). Eric Phipps and David Angus (both of Project DISCOVER) and sckelp may be contacted through ICDVRAT.

# Abstracts

*In alphabetical order, based on first author.*

**Adaptable virtual reality interface for powered wheelchair training of disabled children, I A Adelola, S L Cox and A Rahman**, University of Limerick, Ireland

Childhood development is directly related to being able to independently explore, manoeuvre and interact with one's environment. However, severely disabled children having motor dysfunction often experience impeded motor development, and consequently lack independent mobility. This work relates to the development of the Virtual Environment Mobility Simulator (VEMS) to provide a simple and cost effective choice for powered wheelchair training and rehabilitation. The current area of interest is to study the effects of using real-time wheelchair motion as input for interacting with the home environment. This system provides a home environment delivered on a flat screen computer monitor, and offers simple tasks along with game elements to motivate the user. The widely varied nature of disability, however, requires adaptability of the virtual reality system to specific user training needs. In this paper we propose a conjoint analysis technique to analyse user behaviour, preferences and disability to gear towards the needs of providing an effective training.

**Virtual reality in stroke rehabilitation with the assistance of haptics and telemedicine, J Broeren, M Georgsson, M Rydmark and K Stibrant Sunnerhagen**, Göteborgs University, Sweden

A 3D-computer game was used as a training utility to promote motor relearning on a telemedicine platform in a laboratory setting. The subject suffered from a left arm paresis. He was evaluated before and after treatment with a specific hand function task, a standardized grip force measure test and an upper extremity task. Grip force, endurance and the movement pattern of the upper extremity improved after the treatment. The telemedicine platform allows the professional to record and evaluate progress. The findings implicate that training with Virtual Reality and Haptics can promote motor rehabilitation.

**Assessing stroke patients' ability to remember to perform actions in the future using virtual reality, B M Brooks, F D Rose, J Potter, E A Attree, S Jayawardena and A Morling**, University of East London/Kent & Canterbury Hospital, Canterbury, England

Difficulties in assessing prospective memory (remembering to perform actions in the future) have contributed to a dearth of empirical evidence as to whether stroke patients are impaired at prospective memory tasks. A virtual environment was used to assess stroke patients' and age-matched control participants' performance of realistic event-based, time-based and activity-based prospective memory tasks. Stroke patients were impaired compared to controls at all the prospective memory tasks, but less impaired at the time-based task. Their prospective memory was more impaired than their retrospective memory, assessed by a free recall test. These results will be useful in directing future stroke rehabilitation strategies to focus on specific memory impairments.

**Interaction with shapes and sounds as a therapy for special needs and rehabilitation, T Brooks, A Camurri, N Canagarajah and S Hasselblad**, Kulturcentrum Skaane Lund, Sweden/Universita Degli Studi di Genova, Italy/University of Bristol, Bristol, UK/Emaljskolan, Landskrona, Sweden

Causal interactive audio and visual feedback sourced from whatever faculty is available from children with severe disability and utilised within an adaptable user-friendly interactive environment that encourages, motivates, and is "fun" to participate within has proved to be a rich resource within which to research towards possibilities for the children to reach their fullest potential. This paper details the practical implementation of further (related to earlier work) various visual media; virtual reality; and associated technologies so as to further enhance the study and to verify the feasibility towards a commercial system product.

*Flexible and virtual travel training environments*, **D J Brown, N Shopland and J Lewis**, The Nottingham Trent University, UK

This paper describes the development and evaluation of a virtual travel-training environment for use by people with a learning disability in developing employment related skills. This environment has been designed to work in conjunction with a mobile agent to provide a comprehensive system to prepare and provide real time assistance to people with a learning disability. The evaluation of the virtual travel training environment via a series of case studies has allowed us to advance the development of previously published design guidelines for virtual environments for use by this user group. The next stage of this study is to obtain baseline assessment of the use of these environments before the design and implementation of a range of virtual tutoring agents. Subsequent evaluation of the enhanced environments will allow us to determine the efficacy of such tutoring agents.

*Errorless learning using haptic guidance: research in cognitive rehabilitation following stroke*, **B B Connor, A M Wing, G W Humphreys, R M Bracewell and D A Harvey**, San Francisco State University, USA/The University of Birmingham, UK

This paper presents an approach to rehabilitation of cognitive deficits following stroke using haptic guided errorless learning with an active force feedback (AFF) joystick and computer. While errorless learning (EL) is a proven method of teaching new information to individuals with memory problems, its effectiveness with other types of cognitive and perceptual motor deficits has not been explored. We investigated the effectiveness of haptic guided EL compared to trial and error (errorful: EF) learning on a perceptual motor task with twelve patients who had visuoperceptual deficits following stroke. Individual and group results are discussed.

*Three applications of virtual reality for brain injury rehabilitation of daily tasks*, **R C Davies, E Löfgren, M Wallergård, A Lindén, K Boschian, U Minör, B Sonesson and G Johansson**, Lund University/Lund University Hospital, Höör, Sweden

Part of the process of rehabilitation after a brain injury is the relearning of various daily tasks such as preparing food, managing finances, getting from one place to another and so forth. These tasks require learning on all levels from physical to cognitive. Remembering a PIN code for a bank card, for example, can become automatic and 'in the fingers' after much repetition. However, other tasks require a certain cognitive process, for example, procedures must be followed, quantities estimated, numbers of items remembered or dangerous situations avoided. Even in these cases, repetition of the task many times can help fix the important aspects in the mind. This paper describes three applications of a Virtual Reality based method of rehabilitation which are a part of a larger project to investigate the potential and pitfalls of Virtual Reality technology as a complement to physical training in Brain Injury Rehabilitation. Virtual Reality has the advantage of providing a safe, controlled and highly repeatable environment that a patient can experience in a relaxed manner before having to encounter the potentially dangerous or stressful real environment. The three applications considered here are: kitchen work, an automatic teller machine (ATM) and finding ones way in a complex environment.

*Assessing the utility of dual finger haptic interaction with 3D virtual environments for blind people*, **K Gladstone, H Graupp and C Avizzano**, Royal National Institute of the Blind, London, UK/Scuola Superiore Sant'Anna, Pisa, Italy

Whereas the rapid growth in use of 3 dimensional computer images has proved to be of significant value to many computer users, they have remained totally inaccessible to blind people. The EU GRAB project is seeking to establish the degree to which a dual-finger haptic interface, augmented by audio input and output, can provide non-visual access to this important area of the information world. The haptic interface itself is an entirely new development controlled by a powerful haptic modelling tool. Validation of such a device is a complex procedure, not least because it falls entirely outside of the experience of most users.

*Virtual reality and stroke rehabilitation: a tangible interface to an every day task, D Hilton, S Cobb, T Pridmore and J Gladman, University of Nottingham, UK*

At the University of Nottingham, UK, a project is currently in progress which is exploring the application of virtual environments for supporting stroke rehabilitation. The project has focussed on a user centred design approach and has involved consultation with stroke survivors, therapists and stroke researchers. Seminars held during the initial phase of the project offered an insight into the priorities and perspectives of these individuals, from which we identified the activity of making a hot drink as a suitable every day task to study. Although the longer term aim is to investigate a possible role of a virtual environment to support the rehabilitation of a sequential task, our immediate concern is to select a method of interacting with the virtual environment, which is both appropriate and acceptable for stroke survivors. Responding to a preference for naturalistic action and realistic scenarios, a tangible user interface to a hot drink making activity was piloted with stroke survivors resident in the community. The results of this study have improved our understanding of how stroke survivors interact with simulations and highlighted aspects in need of improvement.

*Real-time clarification of esophageal speech using a comb filter, A Hisada and H Sawada, Kagawa University, Japan*

The only treatment for the terminal symptoms of the laryngeal cancer is to remove the larynx including vocal cords, which mean that the patient loses his voice. Esophageal speech is a method of speech production using an esophagus. An air inhaled in the upper esophagus generates the esophagus vibration to produce a belch-like sound that can be shaped into speech. Although this method has difficulties to be mastered, the voice is able to keep the individuality since the speech is generated by his own vocal organs. This paper introduces a software filtering algorithm which clarifies esophageal speech with the individuality preserved, together with user's evaluations by questionnaires.

*Immersion without encumbrance: adapting a virtual reality system for the rehabilitation of individuals with stroke and spinal cord injury, R Kizony, N Katz, H Weingarten and P L Weiss, Hadassah-Hebrew University, Jerusalem/Chaim Sheba Medical Center, Tel Hashomer/University of Haifa, Israel*

The purpose of this paper is to present results describing the use of a projected, video-based VR system in neurological rehabilitation. The first part describes the adaptation of several of the VividGroup's Gesture Xtreme projected VR scenarios (control of the type, speed, location and direction of all stimuli) and documentation of all subjects' performance. The second part of paper presents initial results in which the system is being used in a clinical study with stroke patients who display symptoms of left unilateral neglect and other cognitive deficits, with those who require balance training as a result of complete or incomplete spinal cord injuries, and young, non-speaking adults who have cerebral palsy and moderate mental retardation.

*Walking aids based on wearable/ubiquitous computing – aiming at pedestrian's intelligent transport systems, T Kuroda, H Sasaki, T Tateishi, K Maeda, Y Yasumuro, Y Manabe and K Chihara, Kyoto University Hospital/Nara Institute of Science and Technology, Japan*

As contemporary transport system including developing Intelligent Transport System (ITS) is vehicle centered, pedestrians especially elders and 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. P-ITS consists of various components including wearable computers for people in special needs and distributed computers to sense and control environments. This paper presents two example components, that is, Intelligent Cane, a wearable computer for the Blind, and a ubiquitous computing system to obtain and visualize traffic flow of Pedestrians.

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

Mental mapping of spaces, and of the possible paths for navigating these spaces, is essential for the development of efficient orientation and mobility skills. Most of the information required for this mental mapping is gathered through the visual channel. Blind people lack this crucial information and in consequence face great difficulties (a) in generating efficient mental maps of spaces, and therefore (b) in navigating efficiently within these spaces. The work reported in this paper follows 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. The main goals of the study reported in this paper were: (a) The development of a multi-sensory virtual environment enabling blind people to learn about real life spaces which they are required to navigate (e.g., school, work place, public buildings); (b) A systematic study of blind people's acquisition of spatial navigation skills by means of the virtual environment; (c) A systematic study of the contribution of this mapping to blind people's spatial skills and performance in the real environment. In the paper a brief description of the virtual learning environment is presented, as well as preliminary results of two case studies of blind persons' learning process with the environment.

*Developing assistive interfaces for motion-impaired users using cursor movement analysis in conjunction with haptic feedback, P M Langdon, F Hwang, S Keates, P J Clarkson and P Robinson, University of Cambridge, UK*

Following a pilot study that suggested that haptic force-feedback could, under certain conditions, lead to 20-50% improvements in time to target in a selection task, a series of experiments further investigated the use of haptic feedback modulated on the basis of cursor position. Improvement in times were obtained for specific haptic assistance techniques, particularly for the more impaired users. Cursor path data was simultaneously collected and found to identify particular features or properties of the motion-impaired cursor movement that can be specifically addressed using modulated haptic force-feedback. This suggests that parameters obtained from temporal and curvature analysis of cursor movements for haptic tasks could be used to set or adapt force-feedback in user interfaces, assisting motion impaired computer users.

*Design of virtual environment input devices for people with moderate to severe learning difficulties – a user-centred approach, T Lannen, D J Brown and P J Standen, The Nottingham Trent University/University of Nottingham, England*

This paper describes the continuation of research introduced in a previous paper: 'Access to Virtual Learning Environments for People with Learning Difficulties', presented by the Authors at ICDVRAT 2000 in Sardinia. The research stems from the development of virtual environments (VEs) for people with learning disabilities and findings of usability difficulties with the computer input devices. The first stage of the study, 'understand and specify the context of use', was achieved by conducting a Usability Context Analysis (UCA), which included an analysis of the user population, task and working environment review. The next stage, before proceeding to concept design, was to identify any existing computer input devices that satisfied the device requirements. No satisfactory match was found. Concept design generated many new concepts through the employment of concept generation methods, which were guided by the design specification. A concept selection matrix was then used to select the best concept against the device requirements. Evaluation of the chosen manufactured concept (VR1) followed. Objectives of this user-based assessment were to evaluate the usability of the new input system, to ascertain whether a User Centred Design methodology is a successful approach. The results of this study show that VR1 has greater usability than the more commonly used joystick and mouse for this user population.

*Finding a place to sit: a preliminary investigation into the effectiveness of virtual environments for social skills training for people with autistic spectrum disorders, A Leonard, P Mitchell and S Parsons, University of Nottingham, UK*

Seven teenagers with an Autistic Spectrum Disorder (ASD) experienced a Single-User Virtual Environment (VE) of a café, with the learning objective of finding a place to sit in different circumstances. Participants also saw a video of real cafés and buses and were asked to choose where they would sit and why. These measures were taken three times: half of the participants received their VE intervention experience between the first and second videos, and the other half received this experience between the second and third measures. Naïve raters coded explanations according to level of social appropriateness. There was a significant improvement in the appropriateness of social observations in the learning of specific objectives in the same café context. Generalisation of learning to a bus context was more difficult and more spontaneous for some individuals than others. Conversations referring to the social scenario depicted by the VE were a great learning opportunity for the participants. This emphasised the importance of the teacher's use of the technology as a teaching tool rather than technology that will directly teach students. The results positively encourage the idea that VR could be a good learning tool for social skills for people with ASD.

*Virtual environments in cognitive rehabilitation of executive functions, C Lo Priore, G Castelnovo and D Liccione, Presidio di Riabilitazione Extra-Ospedaliera "Paolo VI, Casalnoceto/Istituto Auxologico Italiano, Milano/Università di Padova, Italy*

The V.E.Ne.Re. Project (Virtual Executive NEuropsychological REhabilitation) consists in the construction and validation of artificial environments based on Virtual Reality (VR) technologies, aimed for cognitive rehabilitation of executive functions (frontal lobe dysfunction; dysexecutive syndrome). Damasio (1994) pointed at the discrepancy between non immersive artificial lab tests and real life situations to explain the frequent diagnostic and therapeutic failures that occur when traditional cognitive tools are used with frontal patients. In this perspective, VR environments which are capable to generate a better subjective perception of presence and immersivity, become a very promising alternative to enhance cognitive neuropsychology of executive functions. On these premises, we will describe the current three components of V.E.Ne.Re., with special regard to the V-Store software, which consists in a set of tasks aimed to empower executive functions, attention, short term memory, behaviour control and metacognition. V-Store is planned to offer a high level of interaction and to induce time pressure, eliciting subjective managing strategies. The same environment will be used to implement also the virtual versions of two well-known cognitive tests: V-ToL (VR version of Shallice's Tower of London); V-WCST (VR version of the Wisconsin Card Sorting Test). We are currently starting to test our environments, with regards to their clinical efficacy, cost/benefit effectiveness, subjective experience and usability.

*Inclusive design of an interface for a hospital system for information, communication and entertainment, R McCrindle, F Arnold, G Cook, J Barrett and D Booy, The University of Reading/Royal Berkshire Hospital, Reading, UK*

This paper describes the features offered by a hospital portal system for information, communication and entertainment and the work underway to develop an interface to the portal such that all patients regardless of their age, disability, computer experience or native language can use it easily and effectively. The paper discusses the need for inclusive design of the interface to the portal and reports the results and evaluations accruing from the development of the interface to date.

*Research and development project for practical use of robotic travel aid for the visually impaired, **H Mori, S Kotani, K Saneyoshi, H Sanada, Y Kobayashi and A Mototsune**, University of Yamanashi, Kofu/Tokyo Institute of Technology, Yokohama/Musashino Art University, Tokyo/Hitachi Ltd., Hitachi/Nippon Systemware Co. Ltd., Yamanashi, Japan*

Destined to the visually impaired, Robotic Travel Aid (RoTA) acts as an intelligent cart, guiding people across the streets. The 60 Kg, one-meter tall mobile robot is equipped with computer vision system, stereo camera sensor and voice interface. When moving, it is aware of its environment: It recognizes landmarks such as zebra crossing marks or traffic signals, stopping when the light is red, and “sees” cars or other pedestrians. In case of trouble, the robots communicates wirelessly with a Service Center, allowing to give extra information on the trajectory and adapt the navigational information system.

*Virtual reality investigation of strategy formation, rule breaking and prospective memory in patients with focal prefrontal neurosurgical lesions, **R G Morris, M Kotitsa, J Bramham, B Brooks and F D Rose**, Institute of Psychiatry, London/University of East London, UK*

Planning and organisational ability was investigated in 35 patients with prefrontal lesions, using virtual reality (VR) to mimic everyday activity, but in a laboratory setting. A multi-componential VR procedure, the Bungalow Task was developed to test strategy formation, rule breaking and prospective memory. The task involved simulation of decision-making whilst a participant moved around a virtual bungalow, selecting furniture for removal according to specified instructions, and various aspects of prospective memory were tested. Significant strategy formation and rule breaking impairments were observed and additional time and activity, but not event based prospective memory impairment observed. The study demonstrates the successful use of VR as a neuropsychological tool for investigating executive functioning in an ecologically valid fashion.

*Functional magnetic resonance imaging investigation of allocentric spatial memory using virtual reality in patients with anoxic hippocampal damage, **R G Morris, D M Parslow, S Fleminger, B Brooks, V Giometro and F D Rose**, Institute of Psychiatry, London/The Maudsley Hospital/University of East London, UK*

The involvement of the hippocampal formation in spatial memory was explored in two single case studies in which anoxic brain damage had produced selective bilateral damage to this structure. To test spatial memory a virtual reality Arena task was designed, consisting of a circular space surrounded by pattern rendered walls. The participants had to navigate within the arena using a joystick to signal motion. In an encoding phase they had to move towards a pole, situated within the arena. The pole was then removed and they had to move towards where it had been either (allocentric) from a different direction, or (egocentric) from the same direction. Brain activity was recorded during the different phases of the task in control participants and then in hippocampally damaged patients. In the controls, bilateral hippocampal activity was found in the allocentric condition only, with a network of activation in other brain regions, associated with spatial processing in both the allocentric and egocentric conditions. Hippocampal activation was not seen in either of the patients, but the remainder of the network showed normal activation.

*Generation of modifier representation in sign animation, **M Murakami, T Kuroda, Y Manabe and K Chihara**, Nara Institute of Science and Technology/Kyoto University Hospital, Japan*

Most of the Japanese-to-JSL (Japanese Sign Language) translators utilize CG (Computer Graphics) animation to present translation results. However, foregoing systems cannot produce natural and legible sign expressions for the Deaf, because they are based on word-for-word translation. Our research aims to produce animation including proper modifier representation, which can express nuances of original sentences. This paper proposes a method to include modifier representation into animations automatically.

*Exploring the role of virtual environments in the special needs classroom, H R Neale, S J Kerr, S V G Cobb and A Leonard*, University of Nottingham, Nottingham, UK

A series of Virtual Environments (VEs), specifically designed to allow adolescents and adults with high-functioning autism and Asperger Syndrome to practice social skills, have been trialled in a school for students with autistic spectrum disorders. We have taken a qualitative approach to exploring how these programmes might be used to augment traditional teaching practices in a real school. By configuring the VR hardware in different ways and using the programs with various student-teacher combinations we have been able to observe how the VEs are used and to make recommendations as to how they may be modified so they better support teachers and students needs.

*Virtual environment for assessment of rehabilitation equipment, S Nichols, P Frost, S V G Cobb, E Marshall, R Eastgate, J H Park, J Armstrong and C D Ward*, University of Nottingham/Derby City General Hospital, UK

Selection of assistive equipment for use in the home can be difficult. In many cases a variety of alternative designs may be available and it can be hard to determine the most appropriate one to select for a particular patient. The Derby Disability Equipment Assessment Centre (DEAC) provides a needs-led evaluation programme for the assessment of assistive equipment designed for older people and people with disabilities. The primary criteria for each equipment evaluation vary for each project, but often include safety, ease of use, aesthetics and ease of cleaning, as appropriate. DEAC consider the views of the people who use the equipment to be an essential aspect of product evaluation, however, it is not always practicable to have patient representatives visiting the hospital to review alternative product designs. Taking a variety of products to users' homes for assessment can also be problematic from the point of view of manual handling, set up and travel for therapists. Visualisation in a virtual environment presenting raiser combinations with different furniture was proposed to as a potential alternative, speeding up the assessment process and minimising manual handling risks. A feasibility study was conducted jointly between DEAC and the Virtual Reality Applications Research Team (VIRART) at the University of Nottingham to evaluate the effectiveness of a VE as a tool for rehabilitation equipment assessment, taking into account usability and acceptance of the tool by rehabilitation therapists and disabled or older people. This paper presents the findings from a case study example of a chair raiser evaluation and a comparison of results in product selection preferences between real and VE viewing conditions.

*Virtual environments for the assessment of attention and memory processes: the virtual classroom and office, A A Rizzo, T Bowerly, J G Buckwalter, M Schultheis, R Matheis, C Shahabi, U Neumann, L Kim and M Sharifzadeh*, University of Southern California/Fuller Graduate School of Psychology/Kessler Medical Rehabilitation Research & Education Corp./Southern California Permanente Medical Group, USA

Virtual Reality (VR) technology offers new options for 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 that take advantage of the assets available with VR technology. These assets include the precise presentation and control of dynamic multi-sensory 3D stimulus environments, as well as advanced methods for recording behavioral responses. When combining these assets within the context of functionally relevant, ecologically valid VEs, a fundamental advancement emerges in how human cognition and functional behavior can be assessed and rehabilitated. This paper will focus on the progress of a collaborative VR research program at the University of Southern California and the Kessler Medical Rehabilitation Research and Education Corporation. These groups are developing and evaluating VR neuropsychological applications designed to target: 1. Attention processes in children with ADHD within a HMD virtual classroom and 2. Memory processes in persons with TBI within a HMD virtual office. 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 relevant 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 current state of VR technology.

*VirtualAurea: perception through spatialized sound, J Sánchez, L Jorquera, E Muñoz and E Valenzuela,*  
University of Chile, Santiago, Chile

Blind children cognition is currently enhanced by using tactile-based methods such as the Braille system. The use of sound for cognitive purposes is not common in the blind educational community. Even though these facts, an increasingly number of studies are showing that blind children can develop cognitive structures through the interaction with spatial sound. Most studies use specific purpose software to help blind children to construct cognition and learning. A common characteristic of these studies is the absence of robust usability studies that inform of the adequacy and user satisfaction with this sound-based software. This paper introduces VirtualAurea, a flexible software editor for sound-based virtual environments designed “with” and “for” blind children to construct their cognition. It also presents a complete usability study to validate the editor with blind learners by using a kit of cognitive tasks. We also determined the impact of the interaction with this software editor on the development of basic cognitive functions, operations, auditory perception, laterality, comprehensive language, and tempo-spatial orientation mental skills of blind learners.

*Electronic usage of BLISS symbols, N Sándor, G Várady, A Szalmás, C Sik Lányi and Z Kálmán,*  
University of Veszprém/Hungarian Bliss Center, Budapest, Hungary

The desire for communication is every human being's own. It lives in people's mind whose own body deprives themselves of the possibility of relations between people. In the last few decades it was realized that not only the number of people who were kept alive is important, but also their quality of life. One of the base of the prosperities is the ability to adapting themselves to the community. Two different software was made for partially disabled people, using these programs they are able to tell what one has got to say in the easiest and quickest way to their teachers or others, where the point can be a simple conversation, or writing a letter or just a composition. Both application use Blissymbolics, an alternative graphic symbol system that individuals with severe speech and physical impairments find much easier to learn and use than traditional print. First, a Bliss symbols sentence builder serves as a tool for boarders to compose and print Bliss symbol sentences. Second, at the age of the Internet an e-mail reader and writer software was designed especially for Hungarian BLISS users, while the format of the e-mail is compatible with the applications used in international practice.

*An evaluation of the use of virtual environments in improving choice reaction time in people with severe intellectual disabilities, P J Standen and W M D Ip,* University of Nottingham/Queen's Medical School, Nottingham, UK

People with intellectual disabilities are often described as being unable to make choices or decisions. This study set out to test whether choice making or selection from options in a virtual environment would improve the ability of people with severe intellectual disabilities to make decisions or choices in other situations. Volunteers attending an adult training centre were randomly assigned to one of two groups matched on age, sex and ability. The active group ( $n = 9$ ) received six twice-weekly sessions using the virtual environments while their passive partner ( $n = 7$ ) sat next to them watching the computer monitor. Before the intervention all participants completed three tests of choice reaction time which were repeated after the intervention. The active group significantly reduced their choice reaction time on two out of the three tests. There was also a decrease in choice reaction time on the third test however this did not reach significance. In comparison, the passive group showed a non-significant decrease in choice reaction time for only one of the tests. Although these results are encouraging, the study needs to be repeated with a larger group and the collection of additional data.

*Use of virtual environments to acquire spatial understanding of real-world multi-level environments, D Stanton, N Foreman, P Wilson, H Duffy and R Parnell*, University of Nottingham/Middlesex University/University of Leicester/ Scope London, UK

This article outlines experimental work investigating the way that people encode vertical as well as horizontal spatial information from exploration of virtual environments (VEs). We present two studies using simple multi level VEs that provide novel evidence for a vertical asymmetry in spatial memory, where downward spatial judgments are more accurate than upward spatial judgements. The effect was found in able-bodied adults and children, and in physically disabled children. A third study examined transfer of spatial learning from a VE to a real-world equivalent environment using a simulation of a multi-level complex shopping centre with elderly participants. This study confirms the potential of VEs as training media for the elderly.

*Development of a computer controlled cognitive diagnostics and rehabilitation method for the use on the Internet, J Szabo, A Pall, C Sik Lányi and I Pataky*, University of Veszprém/National Centre of Brain Vein Diseases, Budapest, Hungary

In this paper we introduce a computer controlled method (HELP Neuropsychology = HELEN) which enables - as a difference to methods used internationally - not only the establishment of the diagnosis, but permits measurement of the effectiveness of the therapy. It allows

- To produce a database of the patients that contains not only their personal data but also the results of the tests, their drawings and audio recordings.
- It is an intensive therapeutic test which contains tutorial programs too.

*Developments of a peripheral vision system using immersive virtual environment, Y Tabata, M Suga, K Minato, O Oshiro, K Chihara and S Nagata*, Nara Institute of Science and Technology/Shiga University of Medical Science, Japan

Peripheral vision is one of the important vision that human eye has. To measure the peripheral vision is necessary because there is disease process that can affect the peripheral vision such glaucoma. However, the infant or the aged cannot have a peripheral test. They cannot utilize the conventional perimeter system. The authors proposed a newly perimeter system by utilizing Immersive display. This proposed system enables them to have a peripheral test easily.

*Sound-kinetic feedback for virtual therapeutic environments, I Tarnanas and V Kikis*, Aristotle University of Thessaloniki/Kozani University of Applied Science, Greece

This paper reports on the results of a pilot study on comparing auditory feedback to visual and kinesthetic only feedback as the more consistent feedback type that leads to developments in kinesthesia, motor planning, sequencing and timing capabilities. Development of kinesthesia, motor planning, sequencing and timing capabilities is tested through a learning and transfer of learning of a new unusual movement skill task. We defined as new unusual movement skill a target oriented movement performed under specific conditions that do not match real life movements. The participants were 28 learning deficient children 10-12 years of age randomly spread across 3 groups. There was the same number of participants across groups and gender balance within groups. All 3 groups went through two (2) Phases. In Phase I, Learning, the participant practiced the new movement across 8 trials using his/her not prevalent hand. In each trial the target was situated at different positions on the surface. In Phase I, each group performed in a different feedback Condition. In Condition A, the Visual Feedback Condition (VFC), Condition B, the Auditory Feedback Condition (AFC), Condition C, No Feedback Condition, (NFC1) In Phase II, Transfer of Learning, all three groups exercise the task with their prevalent hands in a No Feedback Condition(NFC2). The number of trials available was 4 so as training effects could be inhibited. The results showed that the VFC group performed notably better than the other two groups in Phase I (VFC: 95%, AFC: 15%, NFC: 12%). In Phase II, though, the AFC group performed better than the other two. These results indicate that auditory feedback seems to be a consistent feedback type leading to developments in kinesthesia, motor planning, sequencing and timing capabilities. Kinesthesia, motor planning, sequencing and timing capabilities are associated with mental processing and the development of mental structures on both a conscious and subconscious level developed in conditions where sound information is provided as feedback for movement. Even if the sound feedback ceases to exist the user can navigate his/her movement with the aid of these mental structures. The VE consists of a SGI Octane MXI system, a midi output, a digital camera and two laser pointers. The system was programmed in C and it creates an artificial environment that encodes the user's motion and can translate it into music in real time.

*Distinctive training methods and evaluation of a multilingual, multimodal speech training system, K Vicsi and Á Váry*, Budapest University of Technology and Economics/ELTE Eötvös Loránd University, Hungary

A multilingual, multimodal speech teaching and training system has been developed for 5-10 years old speech handicapped children, in the frame of the SPECO Project, funded by the EU (Contract no. 977126) in 1999. During the training the patients see the speech pictures of the reference speech and listen to the sound of it at the same time. Thus they use the human visual and auditory feedback during their speech learning beside the tactile sensation. A detailed evaluation examination was prepared at the end of the development of the system. Firstly the opinion of speech therapists from different educational field that had been using the SPECO system in their work for a longer period was collected and summarized. Secondly, an objective evaluation was organized to examine the efficiency of the system. It became clear from the objective experiment and from the collection of the opinion of the speech therapists, that the system is a useful and effective teaching aid.

*Developing virtual vending and automatic service machines for brain injury rehabilitation, M Wallergård, M Cepciansky, A Lindén, R C Davies, K Boschian, U Minör, B Sonesson and G Johansson*, Lund University/Lund University Hospital, Höör, Sweden

Two different approaches for developing virtual environments (VE) for brain injury rehabilitation are described and discussed. The two VEs are built with the VR software World Up in the form of virtual vending and automatic service machines. The result from the first approach is a virtual cash dispenser that has been tested on five patients with brain injury. Improving the VE according to the test results was found to be quite hard, since it is implemented in a way that makes it difficult to update the code. In the second approach independent programming modules were identified and isolated. The modules were used to build a VE in the form of a train ticket machine. The second approach seems to provide a fast and understandable way of building virtual vending and automatic service machines for brain injury rehabilitation. There might also be the possibility to add a graphical user interface on top of the modules so that, for example, an occupational therapist with no programming experience could build an arbitrary virtual vending machine.

# Veszprém

## The City of Hungarian Queens

Cecília Sik Lányi

University of Veszprém, Veszprém, Hungary

The town of Veszprém is situated in the Transdanubian part of Hungary, on the border of two regions, between the Bakony Hills and the Balaton-uplands. Veszprém is built on a ridge. The Brook Séd divides the land into low hills, and that is why the town is said to be built on seven hills: Várhegy (Castle Hill), Benedek-hegy (St. Benedict Hill), Jeruzsálem-hegy (Jerusalem Hill), Temetőhegy (Cemetery Hill), Gulyadomb (Herd Hill), Kálvária-domb (Calvary Hill) and Cserhát. Twisting, narrow streets, tiny houses and flowery gardens are the main characteristics of the town.

The thousand-year-old history of the town is concentrated in the Castle. Here is the residency of the Archbishop of Veszprém, in the spectacular baroque-style Bishop's palace, built in 1767. The Archiepiscopal Archives can also be found in the building, where almost 2000 documents are housed from the 11<sup>th</sup>-14<sup>th</sup> century. These ancient documents are really precious especially for researchers, who can get information about life through the ages and details of the inhabitants of the surrounding villages.

The Archiepiscopal Library prides itself on its 60,000 volumes. Bishop Márton Padányi Bíró, who endowed it with 600 books, formed the basis for the collection. In 1751 he had made a catalogue of the books, so when he sent his report to Pope Benedict XIV he could proudly mention the collection in it.

Queen Gizella, the wife of our first king Stephen I, has always been highly appreciated in the town. A museum and chapel are named after Queen Gizella. The Gothic-style chapel was built in the 13<sup>th</sup> century, the walls covered with full-sized frescoes of six Apostles.

The remains of St George's Chapel is a monument of national importance on the north side of St Michael's Cathedral. The relics of the head of St George had been stored here, attracting thousands of pilgrims. The cathedral itself is the central building in the area and in addition to holy masses, concerts and wedding ceremonies are also held here. The now Neo-Romanesque Church is mentioned in the charter of Pannonhalma of the year 1001.

There is a story about the construction of the cathedral, which also gives an explanation of the town's name. Legend has it that the fortune of King Stephen I ebbed away during the building, so Queen Gizella decided to contribute to the expenses herself. She threw away her fur coat ornamented with precious stones and said 'Vessz prém!' ('I let fur lose') with which she wished to symbolize her giving up a luxurious way of life for the sake of the completion of the cathedral. The cathedral served as an important centre of the music life of the Transdanubian region in the 18<sup>th</sup>-19<sup>th</sup> century. Famous European composers' (Mozart, Haydn, Beethoven) pieces were presented not much later than their world premieres.

Besides historical monuments, modern works of art are on display in the Castle area as well. The House of Arts runs three galleries in which contemporary fine- and applied-arts exhibitions are organized. In front of the Holy Trinity Statue an open air stage is built every summer, where concerts and theatrical performances attract the visitors.

From the parapet, where the attractive statues of King Stephen and Gizella were erected on the 900<sup>th</sup> anniversary of King Stephen's death, there is a good view of the north-western part of Veszprém. In the narrow valley one can see hundreds of tiny houses, along with the ruins of the medieval Dominican nunnery named after St. Katherine. This place is also called Margaret-ruins as Margaret, the daughter of King Béla IV was brought up here until the age of ten. The monastery fell victim to the Turkish conquest. Unfortunately only the basement wall and a part of the wall of the church, excavated in 1938, are visible today.

The view from the Fire Tower at the gate of the Castle is fascinating. After the Turkish times the tower was rebuilt for a new purpose: a guard had to watch the city and signal when a fire broke out. Its music clock plays a popular tune every hour. This tower is one of the symbols of the town. Next to the tower there is the former Fire Station, built at the very beginning of the 19<sup>th</sup> century. A short inscription can be read on the

façade referring to the original function of the building: “*This house was built at the inhabitants’ expenses to store fire-fighting equipment*”.

Leaving the Castle area an old Veszprém house can be seen, the so-called Pósa house. The name is taken from that of a printer and bookseller who once owned the building. The Copf style, two-storey building was originally built for the Cistercian order in 1793. On the ledge are vases and two coats of arms. The symbol of the Cistercians is on the left. Not far from here there is another Copf style building, the Kapuváry House, which housed the Town Hall until the beginning of the 1990s. Today’s Town Hall rises on the north-western end of the triangular square. The neighbouring house is the former Veszprém Savings Bank, which was founded by the inhabitants of the town in 1845. The building of the oldest restaurant of the town can be seen opposite the Kapuváry House.

Besides the silent remains of bygone days, the Petőfi Theatre attracts thousands of visitors throughout the year. The Art Nouveau building was built in 1908. It was the first large building in Hungary to be constructed entirely from reinforced concrete. A notable feature is the circular stained glass window at the front.

In the park next to the theatre rises the recently renovated Romantic-style building of the County Library named after Károly Eötvös. The house was originally constructed for the management of the bishop’s estates, and it now it forms an integral part of the University Town.

In Erzsébet Sétány, not far from the County Hall stands the Dezső Laczkó Museum. The name comes from its founder and first director. The exhibitions cover the general history of the region including an archaeological and folk art display. A few metres to the right of the museum there is the so-called Bakony Regional Folk House. It was built in 1935 in the style of a house in Öcs, a village near Veszprém. With its thatched roof and veranda it was considered a very modern one at that time. Inside are items relating to the local peasant way of life and work.

The Kálmán Kittenberger Botanical Garden and ZOO Park – named after the famous Africa-traveller, Kálmán Kittenberger – can be found in Fejes-valley. The park opened in 1958. With grounds of more than 10 acres, it houses 120 species and some 450 animals. Besides species that can be found in every zoo, the park has some zoological rarities, like Sumatran tigers, caracaras and the so-called David-deers.

Above Fejes-valley, on Gulyadomb there is the park which shelters typical Hungarian animals and a Riding School. The aim of the animal-park is to reintroduce once well-known, today forgotten Hungarian species, like the Hungarian grey cattle, black and white Hungarian sheep and typical Hungarian sheepdogs – puli, pumi and mudi.

An other famous symbol of Veszprém is the St Stephan Viaduct spanning above the Fejes-valley. This bridge built at a height of 50 metres above the winding Séd brook and leads to the St László Church.

Besides historic sights and cultural programmes, Veszprém offers recreation for nature-lovers as well. There are countless hiking-routes in the Bakony Hills and several educational paths can be found in the territory of the Balaton-uplands National Park. In the basins and valleys, among the Bakony Hills, tiny villages attract people loving nature and leaning towards romance. Lake Balaton the largest fresh-water lake in Europe lies 14 km to the south of Veszprém.

Although I was not born in Veszprém – I came here only in 1984, after finishing my university studies – my children were already born here, and now I feel to be citizen of Veszprém. I think we live at one of the best places of Hungary. This is partly due to the superb environment, but partly also due to the historic splendour of the city. It is the city of the Queen. The capital, Budapest, is only 120 km away. Despite this we live in a quite smaller city of the country. The lake Balaton and the hilly region of the Bakony are beautiful in all seasons. In the Autumn the red, yellow, green and brown leaves of the trees provide a gorgeous landscape, in Winter the frozen surface of the Balaton is breath-taking, allowing the possibility to skate along the shore. From Balatonfüred, crossing the bay of Tihany, one can reach the peninsula on ice. In Spring, when the ice starts to break, crevasses are formed and huge mountains of ice pool together at the shore of the lake. But the ice soon melts and the new Spring brings thousands of blossoms of splendid colours on trees and flowers in the meadows. During the Summer our part of the country is a real recreation area: you can swim, sail, surf on the Balaton, or hike in the mountains. I tell my sons frequently that we have everything here, our home is in a superb place. I am glad to be an inhabitant of Veszprém, and hope that our guests will feel themselves welcome in our city, and will take home some nice memories of their trip.

# ICDVRAT 2002

## Session I. Virtual Environments for Assessment

Chair: Cecília Sik Lányi



# **Virtual environments for the assessment of attention and memory processes: the virtual classroom and office**

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## **ABSTRACT**

Virtual Reality (VR) technology offers new options for 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 that take advantage of the assets available with VR technology. These assets include the precise presentation and control of dynamic multi-sensory 3D stimulus environments, as well as advanced methods for recording behavioral responses. When combining these assets within the context of functionally relevant, ecologically valid VEs, a fundamental advancement emerges in how human cognition and functional behavior can be assessed and rehabilitated. This paper will focus on the progress of a collaborative VR research program at the University of Southern California and the Kessler Medical Rehabilitation Research and Education Corporation. These groups are developing and evaluating VR neuropsychological applications designed to target: 1. Attention processes in children with ADHD within a HMD virtual classroom and 2. Memory processes in persons with TBI within a HMD virtual office. 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 relevant 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 current state of VR technology.

## **1. INTRODUCTION**

The Virtual Environments (VE) Laboratory at the Integrated Media Systems Center at the University of Southern California (USC) and the Kessler Medical Rehabilitation Research & Education Corp. (KMRREC) continue to evolve research programs aimed at developing virtual reality (VR) technology applications for the study, assessment, and rehabilitation of cognitive and functional processes. This work primarily focuses on the development of systems that address the needs of clinical populations with some form of central nervous system (CNS) dysfunction. These clinical populations include persons with cognitive and functional impairments due to acquired brain injury, learning disabilities and neurological conditions. The rationale for VR applications designed to serve these populations is fairly straightforward. By analogy, much like an aircraft simulator serves to test and train piloting ability under a variety of systematic and controlled

conditions, VEs can be developed that create scenarios that may be similarly used to assess and rehabilitate human cognitive and functional processes. This work has the potential to improve our capacity to understand, measure, and treat the impairments typically found in clinical populations with CNS dysfunction as well as advance the scientific study of normal cognitive and functional/behavioral processes. The unique match between VR technology assets and the needs of various clinical application areas has been recognized by a number of authors (Rizzo et al., 1994; 1997; Pugnetti et al., 1995; Rose, 1996; Schultheis & Rizzo, 2001) and an encouraging body of research has emerged (Rizzo, Buckwalter and van der Zaag, 2002). What makes VR application development in this area so distinctively important is that it represents more than a simple linear extension of existing computer technology for human use. VR offers the potential to deliver systematic human testing and training simulation environments that allow for the precise control of complex, dynamic 3D stimulus presentations, within which sophisticated behavioral recording is possible. When combining these assets within the context of functionally relevant, ecologically valid VEs, a fundamental advancement emerges in how human cognition and functional behavior can be assessed and rehabilitated. This potential was recognized early on in a visionary article (“The Experience Society”) by VR pioneer, Myron Kruegar (1993), in his prescient statement that, “...Virtual Reality arrives at a moment when computer technology in general is moving from automating the paradigms of the past, to creating new ones for the future” (p. 163).

The following report will focus on the development and initial results of our on-going clinical trials using two Head Mounted Display (HMD) delivered VR scenarios: *The Virtual Classroom* and *The Virtual Office*. These scenarios are currently being used to assess attention performance in children with Attention Deficit Hyperactivity Disorder and in the assessment of memory in adults with acquired brain injury, stroke and multiple sclerosis. We will present a rationale for the development and application of each of the systems and a brief description of the methodology that is being applied in the research with these scenarios. Observations will be presented on initial user-centered design evaluation and we will review results from our initial trials with clinical populations. The results presented on the Virtual Classroom ADHD study are from a study conducted at USC and the Virtual Office research is currently being conducted at the KMRREC via a collaborative agreement with USC.

## 2. THE VIRTUAL CLASSROOM

### 2.1 *Rationale for Application with ADHD*

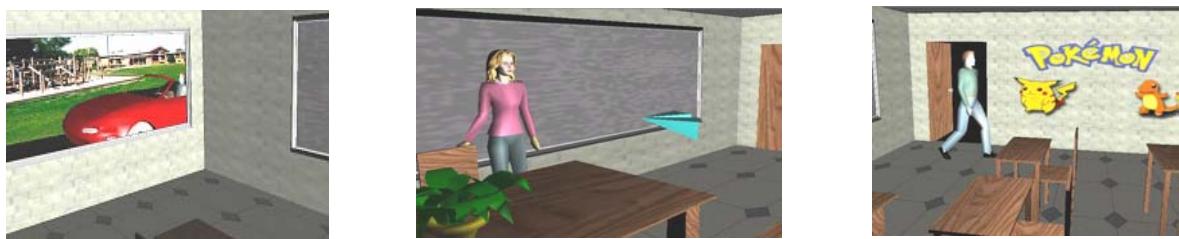
The Virtual Classroom is a HMD VR system for the study, assessment and possible rehabilitation of attention processes. Our efforts to target this cognitive process are supported by the widespread occurrence and relative significance of attention impairments seen in a variety of clinical conditions across the human lifespan. Most notably, attention difficulties are seen in persons with Attention Deficit Hyperactivity Disorders (ADHD), Acquired Brain Injury (ABI), and as a feature of various neurodegenerative disorders (i.e., Alzheimer’s Disease, Vascular Dementia, etc.). VR technology appears to provide specific assets for addressing these impairments that are not readily available using existing methods. VEs delivered via HMDs are well suited for these types of applications as they serve to provide a controlled stimulus environment where attention challenges can be presented along with the precise delivery and control of “distracting” auditory and visual stimuli. This level of experimental control allows for the development of attention assessment/rehabilitation challenges that are more similar to what is found in the real world and could improve on the ecological validity of measurement and treatment in this area.

Our first project in the attention process domain has involved the development of a virtual “classroom” specifically designed for the assessment of Attention Deficit Hyperactivity Disorder (ADHD) in children. The heterogeneous features of ADHD, a behavioral disorder marked by inattention, impulsivity, and/or hyperactivity, have made consensus regarding its diagnosis difficult. Furthermore, traditional methods for assessing ADHD in children have been questioned regarding issues of reliability and validity. Popular behavioral checklists have been criticized as biased and not a consistent predictor of ADHD, and correlations between concordant measures of ADHD, such as parent and teacher ratings of hyperactivity, have been repeatedly shown to be modest at best and frequently low or absent (Abikoff et al., 1993; Barkley, 1990; Colegrove et al., 1999). Due to the complexity of the disorder and the limitations of traditional assessment techniques, diagnostic information is required from multiple types of ADHD measures and a variety of sources in order for the diagnosis to be given (American Psychological Association, 1994; Barkley, 1990; Greenhill, 1998). Thus, in the area of ADHD assessment where traditional diagnostic techniques have been plagued by subjectivities and inconsistencies, it was believed that an objective and reliable VR approach might add value over existing approaches and methods.

## 2.2 Structure of the VR Classroom Scenario

The scenario consists of a standard rectangular classroom environment containing desks, a female teacher, a blackboard across the front wall, a side wall with a large window looking out onto a playground and street with moving vehicles, and on each end of the opposite wall, a pair of doorways through which activity occurs (see Figure 1). Within this scenario, children's attention performance is assessed while a series of typical classroom distracters (i.e., ambient classroom noise, activity occurring outside the window, etc.) are systematically controlled and manipulated within the virtual environment. The child sits at a virtual desk within the virtual classroom and on-task attention is measured in terms of reaction time performance (using a wireless mouse) and error profiles on a variety of attention challenge tasks delivered visually using the virtual blackboard or auditorily via the teacher's voice.

The system is run on a standard Pentium 3 processor with the nVIDIA G2 graphics card. The HMD used in this study was the V8 model from Virtual Research. Tracking of the head, arm and leg used three 6DF magnetic "Flock of Birds" trackers from Ascension Technology Corp. In addition to driving the graphics display in the HMD, the tracking system also served to provide body movement metrics from the tracked locations. These movement metrics are currently being explored as potential measures that may be of value for assessing the hyperactivity component that is sometimes observed in ADHD.



**Figure 1.** Scenes from the Virtual Classroom.

## 2.3 Initial User-Centered Design and Development of the VR Scenario

Early application of user-centered design methods is vital for the reasoned development of any VR application (Hix et al, 1999; Brown et al., 2001). User-centered methods generally require the involvement of the targeted user group in the early design and development phase of scenario development. This involves a series of tight, short heuristic and formative evaluation cycles conducted on basic components of the system. Consideration of user characteristics in this fashion is increasingly becoming standard practice in VR development (Hix and Gabbard, 2002). A clear example of the effectiveness of this approach in promoting usability (and learning) can be seen in the thoughtful work of Brown et al. (1998, 2001) incorporating input from tutors and students with severe learning disabilities in the design of VR life skill training scenarios.

In the user-centered design phase, twenty non-diagnosed children (ages 6-12) tried various evolving forms of the system over the first year of development and their performance was observed while trying out a variety of basic selective and alternating attention tasks. One such task involved having user recite the letters that appeared on the blackboard, while naming the color of the paper airplane that passed by them at random intervals. We also solicited their feedback pertaining to aesthetics and usability of the VE and incorporated some of their comments into the iterative design-evaluate-redesign cycle. Overall results indicated little difficulty in adapting to use of the HMD, no self-reported occurrence of side effects as determined by post-test interviews using the Simulator Sickness Questionnaire (SSQ) (Kennedy et al., 1993) and excellent performance on the stimulus tracking challenges.

## 2.4 Methodology for Initial Clinical Trial

Following the initial user-centered design phase, we conducted a clinical trial that compared eight physician-referred ADHD males (age 6-12) with ten non-diagnosed children. The attention testing involved a vigilance task delivered on the blackboard that required the participants to hit a response button whenever they saw the letter "X" preceded by the letter "A". Two 10-minute conditions were presented to participants: one without distraction and one with distractions (pure audio, pure visual and combined A/V). The distractions consisted of ambient classroom sound, a paper airplane that periodically circled inside the classroom and changed color with each pass, a car that "rumbled" by the window and an avatar that walked into the classroom through one door and exited through a second door (with appropriate footstep and hall-traffic sounds). VR performance (reaction time and response variability on correct hits, omission and commission errors) was also compared with results from standard neuropsychological testing, behavioral ratings by parents on the

SWAN Behavior Checklist (Swanson et al., unpublished manuscript) and on the Connors CPT II (2000) flatscreen continuous performance test. The SSQ (Kennedy et al., 1993) checklist was also administered pre and post VR testing. A detailed description of the full methodology is in preparation for journal submission and is currently available from the first author.

### 2.5 Summary of Initial Findings

The following results were found on the non-VR measures:

- No significant differences were found between groups on age, education, ethnicity, or handedness.
- ADHD participants performed significantly worse than normal controls on the SWAN ( $t(1,16) = -4.55, p < .001$ ) and Connors CPT II Commission error score ( $t(1,16) = -2.37, p < .03$ )
- Data from the standardized psychometric tests and correlation matrices related to VR measures are not presented in this paper due to space limitations and are available from the first author.

The following results were found on the Virtual Classroom measures:

- No significant side effects were observed in either group based on pre- and post-VR SSQ testing.
- ADHD children had slower correct hit reaction time compared with normal controls on the distraction condition (760ms vs. 610ms;  $t(1,16) = -2.76, p < .03$ ).
- ADHD children had higher correct hit reaction time *variability* compared with normal controls on both the no-distraction ( $SD= 220ms$  vs.  $160ms$ ;  $t(1,16) = -2.22, p < .05$ ) and distraction conditions ( $SD= 250ms$  vs.  $170ms$ ;  $t(1,16) = -2.52, p < .03$ ).
- ADHD children made more Omission errors compared with normal controls on both the no-distraction (14 vs. 4.4;  $t(1,16) = -4.37, p < .01$ ) and distraction conditions (21 vs. 7.2;  $t(1,16) = -4.15, p < .01$ ).
- ADHD children made more Commission errors compared with normal controls on both the no-distraction (16 vs. 3.7;  $t(1,16) = -3.15, p < .01$ ) and distraction conditions (12.1 vs. 4.2;  $t(1,16) = -3.22, p < .01$ ).
- ADHD children made more Omission errors in the distraction condition compared to the non-distraction condition (21 vs. 14;  $t(1,14) = -3.50, p < .01$ ). No differences on Omission and Commission errors were found with the non-diagnosed children across no-distraction and distraction conditions.
- Exploratory analysis of motor movement in ADHD children (tracked from head, arm and leg) indicated higher activity levels on all metrics compared to non-diagnosed children across both conditions.
- Exploratory analysis of motor movement in ADHD children also indicated higher activity levels on all metrics in the distraction condition compared to the non-distraction condition. This difference was not found with the normal control children.
- An exploratory analysis using a neural net algorithm trained to recognize a stereotypic leg movement on the first five participants in each group was able to accurately discriminate the remaining subjects to groups at 100%.

### 2.6 Conclusions and Future Directions

The initial results of this study indicate that: (1) ADHD children had slower RTs, higher RT variability, made more omission and commission errors and had higher overall body movement than normal control children in The Virtual Classroom; (2) ADHD children were more negatively impacted by distraction than normal control children; (3) “hyperactive” motor movement metrics were greater in the ADHD group and were more pronounced in this group when in the distraction condition. (4) Virtual Classroom measures showed good reliability; and (5) negative side effects were not self-reported with use of The Virtual Classroom.

At the present time, these data suggest that the Virtual Classroom may have high potential as an efficient, cost-effective and scalable tool for conducting attention performance measurement beyond what exists using traditional methodologies. The system allows for controlled performance assessment within an ecologically valid environment and appears to parse out significant effects due to the presence of distraction stimuli. Additionally, the capacity to integrate measures of movement via the tracking technology further adds value to this form of assessment when compared to traditional analog tests and rating scales. We are continuing to analyze this data in more detail and are currently conducting a follow-up study in the Virtual Classroom on a continuous performance inhibition task. More detailed information on the rationale, equipment, methodology and long-term vision for this project can be found in Rizzo et al., (2000; 2001) and in a detailed paper that is in preparation (Bowerly et al., in prep) that will be available at the time of the ICDVRAT 2002 Conference.

### 3. THE VIRTUAL OFFICE

#### 3.1 Rationale for Virtual Office Application Development

Following our Virtual Classroom application development approach, we are creating other scenarios (i.e., work situations, home environments, etc.,) using the same logic and approach to address cognitive/functional processes that are relevant for a range of other clinical populations. In this regard, we have now constructed a Virtual “Office” environment that evolved from expanding some of the basic design elements of the Classroom VE (see Figure 2). This scenario is generally conceptualized as an “open platform” that could be used to study, test and train a variety of cognitive processes depending on the interests of the researcher.



**Figure 2.** Various configurations of the Virtual Office

#### 3.2 Structure of the Virtual Office Scenario

As with the Virtual Classroom, the user sits at a real desk, but within the HMD, they see the scenes that make up a standard office setting. The virtual desk contains a phone, computer monitor, and message pad, while throughout the office, a virtual clock ticks in real-time, objects appear (and disappear) and a variety of human avatar representations of co-workers/supervisors can be actively engaged. Various performance challenges can be delivered via a “virtual” computer monitor (visual mode), a 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 would 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 concurrent instructions, 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.), avatar activity, events occurring outside the window (e.g., cars rumbling by), or by producing extraneous stimuli that appear in the immediate deskspace (e.g., 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 within a realistic office VE. The same equipment specified for the Virtual Classroom was also used in this scenario.

#### 3.3 Initial User-Centered Design Approach

The Virtual Office scenario has undergone initial user-centered evaluation with normal control, TBI, stroke and Multiple Sclerosis patients similar to that described for the Virtual Classroom. This took the form of having users enter the environment and report on what they observed as they scanned the scenario. Within these trials, participants were asked to explore/scan the office via the HMD for one minute in order to become familiar with the environment. Participants then removed the HMD and were asked to recall the objects that were present in the environment (8 common and 8 uncommon) as an informal assessment of incidental memory performance. Continued memory exposure trials were then conducted with the participants with the experimenter verbally guiding them around the office scenario. Following this guided exploration, the experimenter pressed a key on the system causing the objects to “disappear”. Recall of the objects in the environment was then tested after each trial. User feedback was also solicited to support our ongoing evolution of the scenario components to enhance functional usability, test for side effects, etc. Similar to the Virtual Classroom, we observed good functional HMD use, low incidence of self-reported cybersickness and no difficulty in the visual scanning of the environment by users.

In the course of these initial user trials, it was apparent that clinical and normal control subjects were displaying differing strategies for recalling the objects in the environment. Informal observations suggested that normal control subjects began to use a spatial strategy to assist recall very early the memory trials. This

was characterized by subjects initially turning their heads to the direction of the starting point of the guided acquisition trials. Subsequent recall of the objects then appeared to follow the same order that subjects had been directed to observe them in, from the left side of the office to the right side (Schultheis and Rizzo, 2002). Clinical users were observed to take at least four to five trials before the spontaneous emergence of a spatially organized strategy occurred. This observation served as the impetus to formalize a research design to systematically investigate this process in an initial clinical trial. Essentially what began as an informal evaluation of the users' functional ability to scan and become familiar with the environment, served to produce user behavior that fuelled subsequent hypothesis generation. This lead to a more formalized memory study that is currently being conducted as our first effort at investigating cognitive performance in the Virtual Office.

### *3.4 Rationale for Initial Clinical Trial*

Research over the past 20 years has indicated cognitive impairment to be quite common in TBI (Levin, Gary, Eisenberg, 1990), negatively affecting various aspects of cognitive functioning including attention (Litvan, Grafman, Vendrell & Martinez 1998; Beatty, Wilbanks et al., 1996), information processing abilities (Diamond, DeLuca, Kim & Kelley, 1997; Grafman, Rao, Bernardin & Leo, 1991), and memory functioning (Rosenthal & Ricker, 2000; Brassington & Marsh, 1998). Memory is one of the most consistently impaired functions identified in these populations, with current prevalence rates ranging from 54% to 84% in a TBI population (McKinlay & Watkiss, 1999). In addition, studies have indicated that deficits in memory functioning are a major factor in one's ability to maintain meaningful employment following TBI (McKinlay & Watkiss, 1999). Given the relationship between memory abilities and employment status, accurate and functionally relevant assessment of memory deficits may serve to identify pertinent areas of difficulty, allowing for the creation of interventions that aim to facilitate a return to gainful employment. Traditionally, assessment of learning and memory deficits has been measured through the use of neuropsychological tests. While such assessment techniques are objective, standardized, and very widely applied to neurological disease, neuropsychological assessment procedures have been criticized for providing limited ecological validity. The present study was designed to address this critical limitation via the use of the Virtual Office. Within this virtual environment, the assessment of learning and memory skills in persons with TBI is being conducted within a functionally and vocationally relevant setting.

### *3.5 Methodology for Initial Clinical Trial*

The initial clinical trial with the Virtual Office is currently in progress at KMRREC and aims to recruit 40 participants in total: 20 individuals with moderate to severe TBI and 20 healthy control participants, matched on age, gender, and education. Three major categories of outcome measures will be administered: general questionnaires, neuropsychological measures and the Virtual Office tasks. The Virtual Office is set-up to contain 16 items to be remembered (i.e., target items), which have been placed throughout the scenario. The target items include 8 common items, or those things typically found in an office (e.g., notepad) and 8 uncommon items, or things not typically found in an office (e.g., fire hydrant). Both common and uncommon items were selected so that participants 1) could not inflate their score simply by naming common office items, and 2) to examine differences in learning between more salient or unconventional target items and more common or conventional items. From the perspective of the participant seated at the virtual desk, each side of the room will appear to contain 8 items. In order to balance the distribution of common and uncommon items, placement of target items was determined using three rules. First, items near the participant are all common items typically found on an office desk and items farther from the participant are all uncommon items. Second, the number of common and uncommon items on each side of the room has been counter-balanced. Third, common and uncommon items have been grouped together throughout the office, as would be seen in a typical office (e.g., the telephone is located near the notepad). Common items include: telephone, flower vase, calendar pad, pencil holder, clipboard, stack of books, coffee cup and a framed family photo. Uncommon items include: dog, fire hydrant, stop sign, hammer, blender, guitar, basketball, blender.

The Learning and Recall task examined in this study was designed based on the structure and design of traditional neuropsychological measures. This approach was taken to allow for a more direct comparison between memory performance measures in both the Virtual Office and on standard analog neuropsychological tests. The following are the steps in the procedure for this study.

#### **Incidental Memory Measure**

- Subject "enters" the Virtual Office by putting on HMD.

- Subjects given an audio-guided tour of the Virtual Office. This tour is tape-recorded to control for consistency of descriptions and time in the Virtual Office for the tour.
- Subject then “exits” the Virtual Office. This is achieved by flipping up the “eyeglass” section of the HMD, thereby eliminating the need to remove the entire HMD.
- After “exiting” the Virtual Office, subject is asked: *“Tell me everything you remember from the office”*
- All responses are recorded. The total number of target items recalled serves as a dependent measure of incidental memory.

### Learning Trials

- Subjects “re-enter” the Virtual Office and are guided through the office with the target items being pointed out (verbally) by the examiner. This constitutes a learning trial.
- At the end of the guided tour (learning trial), the subject “exits” the office and is asked to name as many of the target items within the office that they can recall.
- Subject is administered learning trials until they reach the defined learning criterion (successful recall of all items for 2 consecutive trials) or a total of 12 learning trials. This criterion and cut-off is based on previous studies examining learning and memory among individuals with TBI and MS (Deluca et al., 2000).

### Recall and Recognition (30', 90' minute and 24 hour delay)

- Subject is asked to spontaneously recall all 16 target items (outside of the Virtual Office)
- Subject “re-enters” a version of the virtual office (that does NOT include the target items)
- Subjects are asked to verbally recall the 16 target items and point using a 6DF Flock of Birds tracker that actuates a virtual hand, to where the items had been located.
- Cued Recall: Examiner points to location of target items within the Virtual Office using the same hand tracking method that the subject used previously (a 6DF Flock of Birds tracker that actuates a virtual hand), and asks the subject: *1. Was there an object here? 2. What was the object?*
- The principal investigator contacts all participants approximately 24 hours after completing the study protocol in an effort to assess long term recall of the target items

Dependent variables for the Virtual Office task include total number of learning trials required to meet criterion and total number of items recalled and recognized at the designated time delays and a series of “ordering” metrics that will serve to quantify the use of spatial strategies to assist in memory performance. Detailed specification of the methodology of this study is currently available from the first author and results from this clinical trial are expected in early-2003.

## 4. CONCLUSION

The projects briefly summarized in this paper reflect our view that VR technology offers assets that could potentially improve the reliability and validity of methods used in the areas of neuropsychological assessment and rehabilitation. The key elements for this exist in VR’s capacity for consistent delivery of complex dynamic test and distraction stimuli along with more precise measurement of participant responses within the context of functionally relevant simulated settings. In this manner, VR allows for systematic assessment and rehabilitation within simulated “real-world” functional testing and training environments with an aim towards enhancing ecological validity. Such a merger between traditional analog methods with more functional/contextual approaches, if successful, could remedy some of the limitations found individually in these approaches and result in more effective neuropsychological tools. As VR technology becomes more accessible, these applications could have a significant impact on the level of standard care available to clinical populations that are often “bypassed” by advanced information technology developments and this view reflects the current thrust of our work.

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# Use of virtual environments to acquire spatial understanding of real-world multi-level environments

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## ABSTRACT

This article outlines experimental work investigating the way that people encode vertical as well as horizontal spatial information from exploration of virtual environments (VEs). We present two studies using simple multi level VEs that provide novel evidence for a vertical asymmetry in spatial memory, where downward spatial judgments are more accurate than upward spatial judgements. The effect was found in able-bodied adults and children, and in physically disabled children. A third study examined transfer of spatial learning from a VE to a real-world equivalent environment using a simulation of a multi-level complex shopping centre with elderly participants. This study confirms the potential of VEs as training media for the elderly.

## 1. INTRODUCTION

Numerous studies using VEs have demonstrated that spatial knowledge can be effectively acquired from virtual exploration alone, and that such information can be readily transferred to real equivalent environments (see Rose and Foreman, 1999, for a review). With a few exceptions (e.g. Wilson, Foreman, & Tlauka, 1997) most studies of transfer have been based on the horizontal plane, with movements (viewpoint shifts) within the virtual world being restricted to left-right rotation/translation, and forward-back displacements. Most studies have used single storey buildings and subsequent tests of spatial competence have used measures based on way-finding or pointing to obscured targets in the horizontal plane (e.g., Rose et al, 1999; Stanton et al, 1998).

Although many environments used by people with disabilities are constructed on only one level (for example, most special schools are just one storey buildings), in daily life children and adults encounter more complex buildings with many levels (office blocks, shopping centres, car parks), so it is important that spatial learning is not restricted to horizontal spatial relationships. In one of the few studies carried out using a multi-tiered building, Wilson et al (1997) found that, although people could point with some accuracy to objects on a different floor, performance was poorer than when pointing to objects on the same floor.

In a series of studies (Wilson, Foreman, Stanton and Duffy, submitted, a & b) we have examined both horizontal and vertical pointing judgements in a simplified 3-level environment containing multiple targets. We outline these studies and then describe a study investigating transfer of spatial information on both the horizontal and vertical plane in a real-world multi-level building following exploration of an equivalent simulation.

## 2. EXPERIMENT 1 - ADULTS VERTICAL ENCODING

Participants explored a VE consisting of 3 vertically aligned levels, connected by a lift and a staircase. Each room contained two target objects. Following a period of exploration, participants estimated the location up

and across (tilt and rotation) of each object from two viewpoints on every floor in turn. None of the target objects were visible from their testing position (see Wilson, et al, submitted, a).

### 2.1 Participants

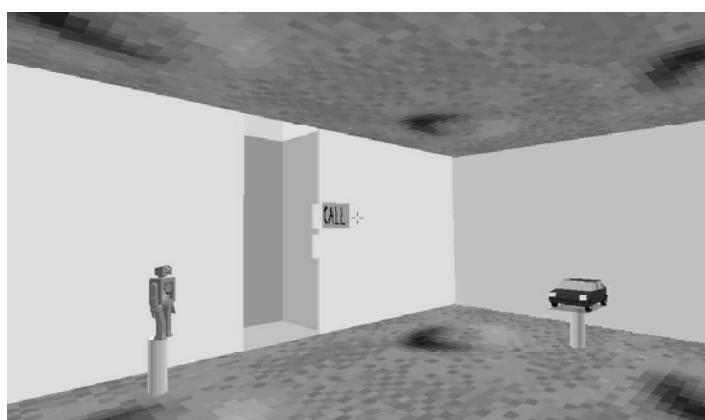
Twenty-seven able-bodied participants with a mean age of 25 years 2 months (range 18-53 years) took part in the study.

### 2.2 Materials

The experimental environment was developed using the Superscape Virtual Reality Toolkit and was presented on a desktop computer. The experimental environment consisted of three vertically aligned rooms, which formed a three-storey building. Each room was a different colour. The rooms were connected by a staircase on one side of the room and an open lift on the other side of the room. Six target objects were located within the environment, two in each room (see figure 1). The relative locations of the objects in the different rooms were counter-balanced across participants.

Following exploration, all the objects were removed from the environment. Six static viewpoints were created, with two viewpoints on each floor in the same relative locations. The cursor keys were used to control pointing using cross hairs in the centre of the screen. The left and right keys enabled rotation movements and the up and down keys enabled tilt movements. Tilt and rotation angles were displayed on an instrument panel at the side of the screen.

A practice environment consisted of an open green space in which a raised brown platform could be reached by lift or stairs. Two target objects were placed within the environment, one on the platform and one on the ground.



**Figure 1.** One of the rooms in the 3-storey simulation containing two target objects

### 2.3 Design and Procedure

Participants were tested individually. First they explored the practice environment and were asked to point to the two target objects, when obscured, to check that they understood the procedure and were familiar with controlling exploration. Then each participant was presented with the 3-storey experimental environment. Exploration started with a view in the middle room, from just in front of the lift facing towards the centre of the room. They were asked to explore all three rooms using the lift and stairs for as long as they wished, and to visit each room at least twice. They were told that the purpose of the exploration was to remember the location of the six objects.

When they were familiar with the objects and their locations, participants were asked to complete pointing tasks. They were told that they were looking at the same VE that they had explored, but with the objects removed. They were told that on some test trials they may need to point up through the ceiling or down through the floor to illustrate the former locations of some of these objects. All participants were tested at each of the six test locations, and from each location they were asked to point towards the former location of each of the six test objects in turn. Test locations and object order were counterbalanced. For each judgment, tilt and rotation angles were recorded (as well as time taken - see Wilson, et al, submitted, a).

### 2.4 Results and Discussion

Errors scores for the tilt and rotation judgements were calculated by subtracting the angles of the participants' estimate of the direction of the target objects from the actual angle. Overall, errors were lower than expected

by chance on all judgements, but poorer performance was found when pointing to upper rather than lower floors. Analysis of the mean absolute tilt errors revealed a significant linear trend,  $F(1,26) = 11.41$ ,  $MSE = 404.75$ ; a planned comparison between upward and downward judgments revealed a significant difference, with less accurate upward than downward judgements  $F(1,56) = 10.71$ ,  $MSE = 383.01$  ( $Ms = 31$  and  $19^\circ$  error respectively).

This is the first experiment to demonstrate that people have a bias in the accuracy of their spatial representations in the vertical dimension, favouring spatial arrays that are lower rather than higher than the horizontal plane.

### 3. EXPERIMENT 2 – CHILDRENS VERTICAL ENCODING

Experiment 1 found that the absolute tilt and rotation errors for adult participants who had explored a multi-storey VE revealed an asymmetry in participants' spatial representations, with more accurate judgements directed to lower rather than higher floors. The presence of asymmetry is particularly important when considering the potential of VE technology for people with disabilities who find it difficult to navigate through large multi-level buildings such as shopping centres and museums, and who might benefit from using a VE to orientate themselves and acquire information about building layouts and facility locations before visiting the real environment. Difficulty in accessing the built environment remains a major factor in limiting the mobility of disabled individuals (Foster, Wenn & Harwin, 1998) and thus educating spatially impaired individuals might in future represent a beneficial application of VE use. Yet large public buildings are typically confusing, specifically because they consist of multiple levels, and so it is important to know whether VEs can be used as a training medium in such situations.

As Stanton et al (in press) found that the effects of restricted mobility can persist from early childhood into adolescence; we tested a group of physically disabled children along with a group of able-bodied children in the same task (Wilson, et al, submitted, b). Our hypotheses were, first, that we might find evidence of vertical spatial asymmetry in children, suggesting that learning this bias occurs earlier than adulthood. Second, we suspected that there might be a difference in vertical orientation ability between able-bodied and physically disabled children due to their different experience of self-controlled exploration.

#### 3.1 Participants

Two groups were recruited from local schools. One group consisted of 12 physically disabled children with a mean age of 8 years and 2 months (range: 5-10 years), of whom 10 were males. All of the physically disabled group had current mobility impairments and had experienced mobility difficulties since birth. Six participants used wheelchairs and the remainder were able to walk with the aid of a walking frame. The second group consisted of 19 able-bodied children with a mean age of 9 years and 5 months (range: 5-13 years), of whom 12 were male. *Materials and Design and Procedure* are as in Experiment 1.

#### 3.2 Results and Discussion

The analysis of the absolute tilt errors revealed a similar pattern to the previous study, in which spatial judgements below the horizontal plane were more accurate than those above the horizontal plane. ANOVA analysis revealed a significant main effect of group,  $F(1, 27) = 6.32$ ,  $MSE = 273.47$ , reflecting greater overall errors in the disabled group ( $Ms = 37$  and  $31^\circ$  error, for the disabled and able-bodied groups respectively), that occurred predominantly when estimating target objects 2-storeys up. This analysis also found a significant main effect of storey,  $F(2, 48) = 14.89$ ,  $MSE = 552.93$ ; no other main effects or interactions were significant ( $p > .1$ ). Planned comparisons on the combined upward versus the combined downward tilt errors found a significant difference, with greater errors for upward judgements,  $F(1, 65) = 8.07$ ,  $MSE = 537.33$  ( $Ms = 42$  and  $31^\circ$  error respectively).

Thus, in both Experiments 1 and 2, absolute tilt errors revealed an asymmetry, with more accurate judgements directed to lower than higher floors, with a suggestion in Experiment 2 that this asymmetry was more pronounced in physically disabled than able-bodied children. Errors of the children overall were significantly higher than those of the adults in Experiment 1 ( $Ms = 33$ , and  $23^\circ$  error respectively).

In summary, the results of these two experiments indicate that participants who explored a 3-storey VE were more accurate in making spatial judgements below the horizontal plane than above the horizontal plane. This is a novel finding which needs to be borne in mind when using VEs for training in multi-storey buildings.

## 4. EXPERIMENT 3 - TRANSFER OF SPATIAL SKILL FROM A SIMULATION TO AN EQUIVALENT REAL-WORLD SHOPPING CENTRE

If skills are learned in a virtual environment it is essential that they transfer to real environments for the experience to be of any real benefit. Although many measures have been developed in VE's, only a limited number of studies have demonstrated effective transfer of training (Linden et al., 2000; Mendozzi, Pugnetti, Barbieri et al, 2000; Rose, Brooks & Attree, 2000; Stanton et al., 2000).

It is of particular interest to know whether older individuals can make effective use of VE technology. In terms of spatial cognition, older individuals have had years of experience in acquiring and interpreting spatial information and of independent navigation in a wide range of environments. However, there are potential limitations to VE use by older individuals that do not apply to other groups. Older individuals may be slower and less dextrous when making motor responses and controlling displacements; their memory may be impaired, and they are less familiar with computers compared with younger age groups (Foreman Stanton, Wilson, Duffy & Parnell, submitted). McDonald et al (1999) found that a group aged around 70 years took twice as long as younger participants to navigate through doorways in a series of virtual rooms, yet they completed the task without difficulty. Rose et al (1999) found that stroke patients aged 25-85 years (mean: 61 years) with a wide range of motor and cognitive impairments, although not as good at acquiring information about building layouts as non-brain-injured controls, nevertheless showed significant spatial learning, particularly when actively directing their own virtual exploration.

In a third study we examine vertical and horizontal encoding using a VE modelled on a real multi level building. It has been suggested that as the population ages, senior citizens might be expected to make increasing use of VE training (McDonald et al, 1999). Since many of the environments that senior citizens may wish to visit, but feel reluctant to visit, are public buildings, the present study took the elderly as a user group and examined exploration in a complex VE public shopping mall, with retail outlets on two levels. Participants understanding of places and routes was then assessed in the real shopping mall. (For a detailed description of this study see Foreman, et al, submitted).

### 4.1 Participants

Thirty-two participants were recruited, of whom 16 had reached retirement age, and 16 were university undergraduates. None had prior experience of the shopping centre. Each age group was subdivided into 8 experimental and 8 controls. The younger groups' mean ages were 26.3 years (range: 21-33) in the experimental group, and 21.75 (range 17-35) in the control group, having 3 and 4 males respectively. The older groups' corresponding mean ages were 73.9 years (range: 62-82) and 74.6 years (range: 64-82), having 2 and 3 males respectively. All had normal or corrected-to-normal vision. All were physically mobile.

### 4.2 Materials

The VE was modelled using Superscape Virtual Reality Toolkit to scale, using the architects' plans. The environment consisted of a two-level shopping centre in Leicester containing over 60 retail outlets (see figure 2). Most outlets line the sides of a wide main concourse. Additionally there are alleyways at either end, also lined with shops, which lead from the concourse toward washroom facilities, restaurants and entrances/exits. At both ends of the shopping centre there is an escalator, stairway and a lift, which were used during exploration to move between floors. The interiors of shops could not be explored.

A hand-held metal pointer attached to two fixed 360° protractors, in the vertical and horizontal planes, was used to point towards the target objects. Participants moved the pointer horizontally and vertically to indicate the horizontal direction and tilt angle of the centre of each target object.

### 4.3 Design and Procedure

Participants in the experimental group explored a simulation of the shopping centre on an individual basis over four days for approximately 30 minutes per day. During each session they explored the VE shopping centre in the presence of the experimenter who checked that they had explored the whole of the environment. During the final two sessions target locations that were to be used for testing in the real shopping centre were emphasised to participants who were asked to remember them. Several were chosen to be ecologically valid, locations which a visitor to the centre would be likely to visit, for example, the post office, chemist and washrooms. Participants acting as controls received no simulation training, but were also taken to the shopping centre and carried out the tasks.



**Figure 2.** The simulation of the shopping centre, which was explored before visiting the real place.

Two days after the final exploration session, all participants were taken to the real shopping centre. Participants were tested individually. They were taken to real locations that corresponded to the viewpoint positions in the VE. Using the hand held pointing device, they were then asked to point to target objects that the VE trained participants had previously seen in the model. These objects were not visible from the testing position. Responses were recorded as vertical and horizontal angles. They were asked to complete this task from four locations within the centre. Six of the obscured targets were located on a floor above, six on a floor below and six on the same floor as the pointing location.

Additional tasks (reported in Foreman et al, submitted) required participants to walk from a starting point to a specific target location and to draw freehand sketch maps of the two floors of shops, incorporating as much landmark information as possible.

#### 4.4 Results and Discussion

Compared with control groups who made guesses, both undergraduate and senior citizen experimental groups were more accurate in making pointing judgements toward non-visible targets,  $F(3,28) = 12.61$ ;  $p < .001$ , post hoc Tukey tests revealed that both experimental groups were significantly more accurate than their corresponding controls (students:  $p < .006$ , senior citizens:  $p < .001$ ). The student and senior citizen experimental groups were not significantly different from one another ( $p > .5$ ).

Analysis of the judgements of level (below versus same for upper, and above versus same for lower, floor pointing locations) showed that experimental groups indicated the correct level (students: 75.7%, senior citizens: 60.4%) more often than controls, who scored at chance (students: 50.0%, senior citizens: 50.7%). When the two experimental groups were compared with the combined controls, groups differed significantly,  $F(2,29) = 24.5$ ;  $p < .001$ . Student and senior citizen experimental groups both scored higher than controls (both  $p$ 's  $< .001$ ) but the two experimental groups also differed, students scoring higher ( $p < .01$ ). Two out of eight senior citizens in the experimental group performed at chance level throughout.

Despite the widely accepted notion of deterioration of spatial functions with age, this study shows that many elderly people remain spatially competent and that age is not a barrier to the beneficial use of simulated environments for training. Wider use and adaptation of this technology might improve social inclusion in older populations by encouraging their confident use of public buildings. The present results suggest that a VE can be used beneficially not only by younger participants, but also by the elderly to enhance their spatial knowledge of an unfamiliar public building.

## 4. CONCLUSIONS

We have discussed two studies using simple multi level VEs. The data from these studies provides novel evidence for a vertical asymmetry in spatial memory, where downward spatial judgments are more accurate than upward spatial judgements in adults, able-bodied children, and children with physical disabilities. It will

be interesting to examine this effect in a real-world environment. The results of these studies have important implications for multi-level VEs for training. A third study examined the use of a simulation of a multi-level complex shopping centre for training. Elderly people's spatial knowledge in the real-world shopping centre was examined following exploration of the simulation. This study indicates the potential of VEs as a training medium for the elderly. More work needs to be carried out to examine vertical spatial judgments in this type of complex environment.

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# An evaluation of the use of virtual environments in improving choice reaction time in people with severe intellectual disabilities

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## ABSTRACT

People with intellectual disabilities are often described as being unable to make choices or decisions. This study set out to test whether choice making or selection from options in a virtual environment would improve the ability of people with severe intellectual disabilities to make decisions or choices in other situations. Volunteers attending an adult training centre were randomly assigned to one of two groups matched on age, sex and ability. The active group (n = 9) received six twice-weekly sessions using the virtual environments while their passive partner (n = 7) sat next to them watching the computer monitor. Before the intervention all participants completed three tests of choice reaction time which were repeated after the intervention. The active group significantly reduced their choice reaction time on two out of the three tests. There was also a decrease in choice reaction time on the third test however this did not reach significance. In comparison, the passive group showed a non-significant decrease in choice reaction time for only one of the tests. Although these results are encouraging, the study needs to be repeated with a larger group and the collection of additional data.

## 1. INTRODUCTION

A common perception of people with intellectual disabilities is that they are unable to make choices or decisions. This inability prevents them from playing a fuller role in society and maintains their dependence on staff or other care givers (Cooper and Browder, 2001) and has been cited as a barrier to making informed decisions about the health care they wish to receive (Welsh Health Planning Forum, 1992) and their ability to give eye witness testimony (Clare and Gudjonnsen, 1995). Cooper and Browder (2001) see this characteristic as resulting from a constant denial of choice which underlies their inability to respond to stimuli in the community and as a result they may never acquire skills that lead to enhancing their independence. Additionally, they believe limited opportunities to make choices may result in the expression of frustration in the form of aggressive behaviour or withdrawal. Reduced intellectual capacity need not necessarily lead to the inability to make choices as even people with severe and complex disabilities can express stable preferences when provided with choices (Lancioni, O'Reilly and Emerson, 1996).

The rationale for replacing traditional forms of institutional provision with small community based residential support, as well as being financial, included a belief that this move would facilitate both inclusion and self-determination (Robertson et al (2001). However, while there is considerable evidence to suggest that people in smaller community based residential settings may experience greater choice than people in larger more institutional settings, opportunities are still highly restricted (Robertson et al, 2001).

Cooper and Browder (2001) demonstrated how embedding choice opportunities in a trip to a fast food outlet can enhance choice making. They set out to increase the opportunities for choice making in a group of eight people with severe intellectual disabilities with a staff training package. Equating choice making with the selection of options, they trained staff to offer a series of two options (eg which of two doors through which to enter; two photos of food or drink options) when using fast food restaurants. Compared with baseline, the people with intellectual disabilities increased the number of choice responses they made both

prompted and independent. They also required a much lower level of prompting to make these choices after the intervention.

The implications of this study are that carers of those with intellectual disabilities need to present them with options on as many occasions as possible. However, what is the best way to increase the number of times options are presented? Options presented by staff and carers in day to day activities may well be the most ecologically valid way of increasing the opportunities for choice-making. However, staff are often pressed for time, wary of letting their charges take risks and may also find it difficult to suppress their natural inclination to take over before allowing the person sufficient prompts for them to perform the selection independently. Pantelidis (1993), talking about their role in education, claimed that virtual environments encourage active involvement: if the user remains passive nothing will happen. In common with other interactive software the user is constantly faced with making choices or decisions about what action to take next eg whether to move or remain stationary, which direction to go, which object to select. Standen and Low (1996) found that in initial sessions school aged students with severe and profound intellectual disabilities needed much assistance and prompting from a tutor to use desk top virtual environments. After repeated sessions, however, the amount of self directed interaction with the computer increased and the amount of help they required from the tutor decreased. If this self-directed activity in a virtual environment takes the form of making choices or selection from options, would this improve the ability of people with severe intellectual disabilities to make decisions or choices in other situations? The present study set out to answer this question.

## 2. METHODS

### 2.1 Participants

Twenty-five people with severe intellectual disabilities were invited to take part. They attended the adult training centre where the research was taking place. The criteria for approaching them was that they had not taken part in any of our earlier studies using virtual environments and that they had sufficient motor and visual ability to use the monitor and controls. Two refused the invitation because of their dislike of computers and one had behavioural problems that led his keyworker to advise that activities that were unsupervised by a member of staff from the day centre would be unwise. In order to match the groups as closely as possible, the remaining twenty-two were grouped into 11 pairs matched on age, sex, British Picture Vocabulary (a measure of verbal ability) and Raven's Matrices (a measure of non-verbal ability) scores and presence of additional physical disabilities. Members of each pair were then randomly assigned to either an active or passive group. Following matching six participants dropped out. Two decided they would not like to continue, two had clashing commitments, one moved from the area and one was found to have taken part in an earlier study. This meant that two individuals from the active group were without a matched partner. Details of the participants are shown in Table 1.

**Table 1.** *Characteristics of participants and dropouts*

	All participants n = 16	Active group n = 9	Passive group n = 7	Drop out n = 6
Mean age (median)	43.1 (46.5)	41.6 (44.0)	45.0 (52.0)	Unavailable
Sex ratio m:f	9:7	5:4	4:3	1:5
Mean (median) BPVS score	59.0 (55.0)	65.2 (56.0)	51.0 (54.0)	54.2 (69.5)
Mean (median) Ravens Matrices score	8.5 (7.0)	10.4 (13.0)	6.0 (6.0)	12.7 (12.0)
Presence of physical disabilities	4	1	3	0

As the data were skewed, the groups were compared for age, BPVS and Ravens Matrices scores using the Mann Whitney U test. In spite of the passive group having a higher median age and lower median scores on the Ravens Matrices, no significant differences were found.

## 2.2 Design

The experimental group interacted with virtual environments while their matched controls sat at their side and watched. The groups were then compared on change from baseline performance on two choice making tasks.

## 2.3 Measures

**2.3.1 Card game.** This contains ten cards each depicting a familiar object (eg apple, fish) and the participant's recognition of the objects is first ascertained. Each of the ten cards has a common pattern on the other side. A trial involves the cards being placed face down displaying the common pattern and this activity is screened from the participant so they cannot see the identity of the cards or their location. The participant is then asked to guess where one of the objects is. Time to touch the card that is chosen is recorded in seconds and the card is then turned over so that the object on the other side is visible. If it is not the target object and the person wishes to have another attempt they can do so but this attempt is not timed. This process is repeated for each of the ten objects. After each trial the cards are reshuffled. The times for the ten trials are averaged for each participant producing a single score for this test.

**2.3.2 Shopping list.** This is a computer based shopping list with ten categories of items (eg vegetables, drinks) pictorially represented. A trial involves the participant being shown one of the lists before being asked to choose two items by pointing at them on the screen. The time taken to choose the second item is recorded. This process is repeated for each of the ten shopping lists and the times for the ten trials are averaged for each participant. To avoid habitual responses, on three trials, after the time for the second choice has been recorded, participants are told that one of the items is no longer available and they have to choose something else. The time taken to make the alternative choice in seconds is recorded and the three times are averaged for each participant. This task therefore yields two scores: one for the initial choice (an average of ten) and one for the alternative choice (an average of three).

## 2.4 Virtual Environments

Participants used the café, supermarket and factory from the Virtual City (Brown, Neale and Cobb, 1999). These were developed as part of a project sponsored by the National Lottery Charities Board. Participants navigated through the environments using a joystick and interacted with objects using a standard two button mouse. In the Café the participants had to choose where to sit and order drinks and snacks from a pictorial menu. In the Supermarket they had to select items from the shelves, put them in the trolley and take them to the checkout. In the Factory they had to select the correct clothing from a wardrobe before entering the two storey factory where they had to find a number of COSSH (health and safety) forms and identify a series of hazards while avoiding a trolley that moved back and forth between clearly marked hazard lines.

## 2.5 Procedure

All participants were assessed at baseline on the two tasks to assess choice making: the card game and the shopping list. The active group then had six 20 to 30 minute sessions over the next three weeks using the Virtual City. Initially they needed help from the researcher (DI) to use the environments but in later sessions they were able to use them with minimal help. For seven participants in this group their matched pair from the control group sat alongside them during these sessions to control for the amount of time the participants spent doing something different from their usual activity and in the presence of the researcher. After the last session was completed, all participants repeated the card game and the shopping list.

## 3. RESULTS

As data were normally distributed, unpaired t-tests were used to compare the scores of the active group with those of the control group. Baseline scores were compared with post intervention scores using paired t-tests. Results from all 16 participants are presented.

### 3.1 Card game

For the card game there was no difference between the two groups at baseline or post intervention. However only the active group significantly ( $t = 4.12$ ,  $df = 8$ ,  $p < 0.003$ ) reduced their time to make a choice from baseline (see Table 2.).

**Table 2.** Mean times in seconds for the active and passive groups on the card game.

	Active n = 9	Passive n = 7
Mean time for baseline (SD)	3.76 (1.11)	4.59 (2.03)
Mean time for post intervention (SD)	2.43 (0.72)	3.46 (2.51)

### 3.2 Shopping List

For the initial choices of the shopping list the active group was significantly ( $t = 3.66$ ,  $df = 14$ ,  $p < 0.003$ ) slower than the passive group. However, again only the active group significantly ( $t = 4.19$ ,  $df = 8$ ,  $p < 0.003$ ) reduced their choice reaction time from baseline to post intervention.

For the alternative choices for the shopping list there was no significant difference between the two groups either at baseline or post intervention. However, although the results did not reach significance their mean scores indicated that the active group improved from baseline (mean = 6.73 seconds) to follow up (mean = 3.98 seconds) while the passive group became slower with a mean of 4.42 seconds at baseline and 5.95 seconds at follow up. Mean times in seconds for both groups are shown in Table 3.

**Table 3.** Mean times in seconds for the active and passive groups on the shopping list

	Active n = 9	Passive n = 9
Mean time for baseline initial choice (SD)	16.58 (3.18)	11.02 (2.78)
Mean time for post intervention initial choice (SD)	12.46 (4.30)	11.08 (3.90)
Mean time for baseline alternative choice (SD)	6.73 (3.75)	4.42 (1.64)
Mean time for post intervention alternative choice	3.98 (2.18)	5.95 (3.18)

## 4. DISCUSSION

After several sessions interacting with the virtual environments participants significantly reduced their choice reaction time on both the card game and the initial choices on the shopping list. There was also a decrease in this measure for the alternative choice on the shopping list, however this did not reach significance. In comparison, the group who watched showed a decrease in choice reaction time for the card game which did not reach significance, no change on the initial choice reaction times and an increase in alternative choice reaction times on the shopping list.

This result was somewhat surprising as with the small sample size, short intervention time and non-standardised tests no significant differences were expected. Of the three tests, it was expected that the one where participants were forced to make an alternative choice would be the one most likely to show an effect if the active exposure to virtual environments were improving the participants' decision making. The other two tests could merely be a measure of simple reaction time rather than choice reaction time as their choice in both situations could be habitual. The improvement in the expected direction in the alternative choice on the shopping list may have failed to reach significance because of the small sample size or that the test was not measuring choice making. On the other hand it may be because the intervention failed to have an effect on choice making. If this is the case, how could the improvements on the other two measures in the active group be explained?

One possibility is that although the passive group was physically passive they may not have been psychologically passive. This distinction was utilised in a study by Wilson, Foreman, Gillett and Stanton (1997) who investigated the effect of exposure to a simulated environment on an orientation task in the same environment. Their participants worked in two types of pairs. In one pair one participant explored the simulated environment using the interaction devices (physically and psychologically active) while the other

participant watched passively (physically and psychologically passive). In the other type of pair one participant gave instructions (physically passive, psychologically active) to the other (physically active, psychologically passive) on what routes to take. In the present study, the passive partner was told to refrain from giving guidance or making suggestions to the active participant. Passive participants found no difficulty in following this instruction. However, in order to ensure their continuing participation, they had been promised sessions using the virtual environments after the active participant had finished the study. This may have led them to become psychologically active, mentally rehearsing some of the tasks they anticipated. Even though psychological activity could not have been eliminated, it is unlikely to have been an influential factor as choice reaction times for the passive group only decreased in the card game and this decrease did not reach significance. There was considerable variability in choice reaction times and for the passive group this variability often increased post intervention. It may therefore have been that for some individuals in this group their choice reaction times were decreasing post intervention and psychological activity may be responsible.

An explanation that cannot be ruled out is that as a result of their active involvement in the virtual environment, the active group became more confident in the testing situation. It is difficult to envisage what control activity would eliminate this possibility while still controlling for time in the test situation and exposure to the same visual information.

While these results are promising, they need to be confirmed in a future study with a much larger group of participants. Future studies would also benefit from collecting additional types of data. In many of our studies we utilise video recordings to measure how much help participants are receiving (Standen, Brown, Proctor and Horan, 2002) and current versions of the software collect data on the user's activity. Neither of these were available for the present study so that there was no precise information about how many choices each active participant was making while using the virtual environments nor whether this increased with repeated sessions. Analysis of this source of information would demonstrate whether some of the active participants were not really very active in terms of the number and the types of choices they were making in the virtual environment. For example, some choice making in the virtual environments was more similar to the tests of choice reaction time than were others. Ordering drinks and snacks in the café shared some similarities with the shopping list, while searching for forms in the factory focussed more on decisions about which direction to take. This information could then be linked to the change in their choice reaction times from baseline to post intervention.

Additional data from the tests of choice reaction time would also be informative. Recording time alone gives no information about the activity preceding the choice. No distinction can be made between a long reaction time due to a latency to initiate an arm movement and one where the participant's hand has hovered over several items before settling on a choice. For the shopping list no note was made of what items were chosen on the alternative choice and whether they bore any relation to the item that was "unavailable" (eg choosing another soft drink rather than coffee) or whether they were totally unrelated. Choosing unrelated items would suggest that choices were being made randomly rather than reflecting some type of strategy.

As a postscript, an attempt was made to repeat the study incorporating some of the changes in design mentioned above. This time it was impossible to persuade participants in the passive group to either continue with the study because they became despondent at not being able to use the computer or to refrain from intervening with their partner's performance.

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# ICDVRAT 2002

## Session II. Speech and Communication

Chair: Tomohiro Kuroda



# Generation of modifier representation in sign animation

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## ABSTRACT

Most of the Japanese-to-JSL (Japanese Sign Language) translators utilize CG (Computer Graphics) animation to present translation results. However, foregoing systems cannot produce natural and legible sign expressions for the Deaf, because they are based on word-for-word translation. Our research aims to produce animation including proper modifier representation, which can express nuances of original sentences. This paper proposes a method to include modifier representation into animations automatically.

## 1. INTRODUCTION

Sign Language is a native language for the Deaf. To establish smooth communication between the Deaf and the hearing people, many researches have been developing systems, which can translate Japanese and JSL mutually (Sagawa et al, 1996; Kato et al, 1997).

Foregoing Japanese-to-JSL translation systems mostly use 3D CG animation, called sign animation, in order to present Sign Language. Most of sign animations are concatenations of short animation corresponding to given word. Although transitions between short animations are smoothly interpolated, conventional sign animations cannot express the changes of motion duration and speed. It is indispensable to include these elements into sign animation; otherwise, sign animation comes quite dull expressions without any modulation for the Deaf, like a robot voice for the hearing people. Kurokawa et al (1997), Igi et al (2001) are developing translation system, which enables editors to add modulation on sign animations manually. Automatic generation method of adding modulation into sign animation is important factor for establishing automatic Japanese-to-JSL translation system in the near future.

This paper takes up hand movement mainly, and proposes the method to include modifier representation into sign animation by means of determining patterns of motion.

## 2. PROPOSED METHOD TO INCLUDE MODIFIER REPRESENTATION

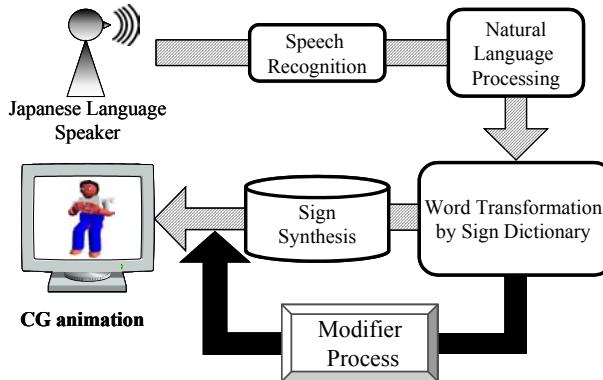
### 2.1 *Modifier Representation*

JSL is expressed via many channels such as hand motion, finger alphabet, facial expression, mouth movement and nod et cetera. All elements have important meaning to convey what signer's want to say. A sign word can be expressed by totally different hand motion and expressions to give some modulations.

Two types of modulation; emotional expression and modifier representation can be found on JSL. Emotional expression is given by signer's feeling. For example, when people get angry, they speak with asperity. Such expressions don't appear on written sentence. To the contrary, modifier representation shows qualifiers to modulate meaning of other words. Thus, modifier representation actually appears on written sentence as a word. However, foregoing studies consider modulation as emotional expression, and modifier

representation isn't being taken into consideration with sign animation. This seems the one reason why sign animations are not natural and legible. This paper focuses on modifier representation and proposes the method to include it into sign animation.

Oblique arrow in Fig. 1 shows typical process flow of foregoing system that translates into JSL from Japanese. Firstly, spoken Japanese sentence is converted into a train of words by morphological analysis. For example, the system translates the sentence 'this book is very cheap' into concatenation of four words 'this', 'book', 'very' and 'cheap'. Secondly, each Japanese word is replaced with corresponding sign word one by one, and synthesizes them smoothly.



**Figure 1.** Structure of Translation System Including Modifier Representation.

However, as this method is a verbatim translation, cannot produce natural sign animation. In former example, the Deaf don't represent the word 'very'. They express 'cheap' with exaggerated gestures to convey the meaning 'very'. Thus, the Deaf add adverbial meanings by changing expression. This research adds modifier process shown by black arrow. In case where the qualifier appears on the sentence, adjectival movements change based on the degree of emphasis.

## 2.2 Classifications of Modifier Representation

To standardize the labels of JSL and to handle signs easily on computers, the romanized notational system for JSL is proposed. This system is named Signdex and recorded 545 words as version 1 (Kanda et al, 1997). We picked adjectives recorded on Signdex V.1 as object. Changes of the motion are examined, in case these adjectives are modified by degree adverb like 'very'. We are concerned here only with words that move simply like linear motion, to extract modifier representation more easily. This research ignores the modifier representation given by facial expressions.

**Table 1.** Classification example of each adjective emphasized by degree adverb.

Signdex	Sample Sentence	"Range"	"Speed"	"Frequency"
aSAI (shallow)	This pond is shallow.	○		
uTSUKUSHII (beautiful)	This flower is beautiful.	○		
oSOI (slow)	That car is slow.		○	
oMOI (heavy)	This stone is heavy.	○		
oMOSHIROI (interesting)	This program is interesting.			○
Tanoshii (pleasant)	Excursions are pleasant.			○
tOOI (far)	Your house is far.	○		
nAGAI (long)	This bar is long.	○		
hAYAI (fast)	That car is fast.		○	
fUKAI (deep)	This pond is deep.	○		
yASUI (cheap)	This book is cheap.	○		

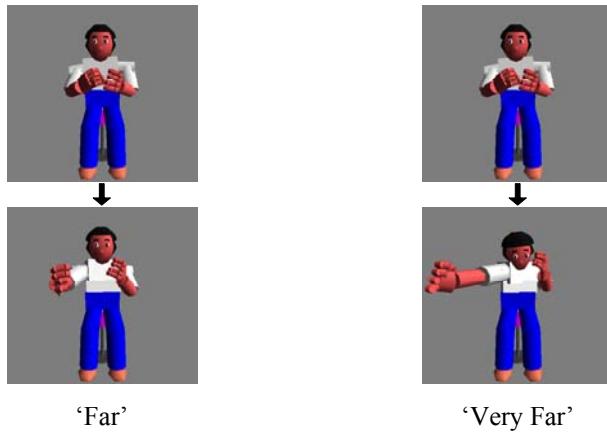
It becomes clear that native signers express degree adverb by varying movement's, "Range", "Speed" and "Frequency" of adjectives. For example, 'very far' is expressed by extending movement's "Range" of 'far'. The proposed method introduces several grammatical rules and varies three features in sign animation. Where grammatical rule is to develop a certain pattern about degree adverb. For instance, it assumes that 'very' doubles "Range" of 'far'. In case 'very far' appears on sentence, the system produces animation of 'very far' using animation 'far' with rule "Range" and parameter '2'. Thus, definition of rule at each set of

degree adverb and adjective makes dictionary small, because there is no necessity to register animation corresponding with all emphasized expression. The example of a classification result is shown in Table 1. Even the same words in Japanese, sometimes there are some different expressions in JSL. In that case, we select the expressions, which are recorded in Signdex V.1.

### 2.3 Analysis of data

Original sentences (which include only adjective like sample sentences shown in Table 1) and emphasized sentences (which are modified by ‘very’) are acquired by motion capture system, S-TEL. This system obtains whole upper body motion using three sensor units; two gloves and a headset. The gloves obtain hand posture and 6D trackers attached to wrists and head obtain positions and orientations of wrists and head (Kuroda et al, 1998).

An informant wears sensors and expresses sentence given by Japanese text. Number of informants is one. In addition, he isn’t told that the experiment pays attention to the movements of hands mainly, and expresses JSL sentences as usual. Fig. 2 shows the example of acquired animation.



**Figure 2. Example of Captured Sign Animation.**

We cut sign motion corresponding target word from obtained data and analyze it. In this report, we analyze “Range” and “Speed” among the three features.

“Range” is analyzed by PCA (Principal Component Analysis) to examine the amount of change of the data by emphasis. PCA is widely used in signal processing, statistics and neural computing to reduce the dimension of the data. Analysis reveals the direction depending on the movement of wrists and head. Firstly, position information about both wrists and head are analyzed separately, and their trajectories are detected. Secondly, original and emphasized words are mapped on the axis of the first primary component of the original word. Comparing original word with emphasized word, the ratio of the distance is detected.

**Table 2. Ratio of “Range” and “Speed”.**

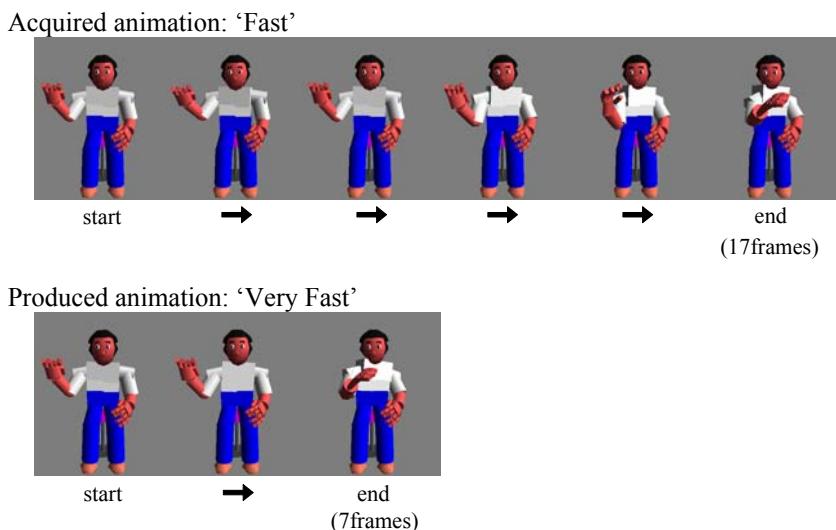
Adjective	“Range”			“Speed”
	Right wrist	Left wrist	Head	
shallow → very shallow	5.35	2.25	1.45	0.89
beautiful → very beautiful	1.83	3.49	2.38	1.00
slow → very slow	1.00	1.01	0.57	1.93
heavy → very heavy	1.19	1.40	2.94	1.88
interesting → very interesting	1.06	1.24	8.12	0.78
pleasant → very pleasant	1.86	1.89	9.37	1.00
far → very far	1.75	2.06	6.42	1.00
long → very long	2.16	2.22	1.53	1.68
fast → very fast	0.75	2.03	2.33	0.41
deep → very deep	1.02	0.68	1.16	1.57
cheap → very cheap	2.53	1.30	1.54	1.83

(Original word is made 1)

“Speed” is compared number of frames between original words and emphasized one. Each parameter to emphasize original word using degree adverb ‘very’ are shown in Table 2. The results differ from pre-classifications. Although certain words are classified into only “Range” in forecast, it become clear that these words vary number of frames actually. The same is true of “Speed”.

#### 2.4 Producing of Animation

Using of the obtained ratio, sign animation including modifier representation is generated. To emphasize “Range”, coordinate value of original word is multiplied by each ratio. The first frame of original word is made a standard point (initial position of movement) of emphasized word. To emphasize “Speed”, number of frames is increased or decreased. When speed of motion becomes slow, presenting the same animation at a regular interval increased the number of a frame. To the contrary, when speed becomes fast, cutting out some images at a regular interval reduced frames. Fig. 3 shows the produced sign animation including modifier representations by varying “Range” and “Speed”.



**Figure 3.** Generated Sign Animation emphasizing “Range” and “Speed”.

## 3. EVALUATION VIA READING TEST

### 3.1 Legibility of Sign Animation

The experiment aims to confirm that modifier representation is easier to understand than verbatim translation. 23 test subjects participate in this experiment; 1 of them is the Deaf, 4 of them are hearing impaired midway and others is the hearing people who has 1 to 30-years experience in JSL. 18 subjects among 23 are a first time to watch sign animation.

Two kinds of sign animations, one is word-for-word translated animation and the other is produced by the proposed method are presented.

#### [Steps]

1. Japanese sentence is shown by text.
2. Word-for-word translated animation (animation A) is presented.
3. Animation including modifier representation (animation B) is represented.
4. Subjects evaluate legibility of two animations.

There are five selections of answer on questionnaire, that is, “A is much better”, “A is better”, “same”, “B is better” and “B is much better”, and scored from 0 (“A is much better”) to 4 (“B is much better”), and the subjects tick off one of them. Score 0 means that animation A is more legible than animation B, and score 4 means that animation B is more legible. As a result of average, it become clear that animation B is more natural and legible for subjects except for one case, which regarded as the same legibility.

This seems attributed to the factor that the difference does not change according to adjective. For example, a sentence ‘This flower is very beautiful’ got score 2. This result means that there is no difference between two animations. Hereafter, it needs to check about more adjectives.

### 3.2 Various Modifier Representations

This experiment confirms that proposed method can generate various expressions by varying only several parameters. According to observation in Sign Language Club, the Deaf uses many degree adverbs such as ‘very’, ‘extremely’, ‘a little’, ‘slightly’, and so on. Varying parameters produces some modifier representations corresponding to these degree adverbs. Temporarily, order of degree is defined following.

slightly < a little < (original) < very < extremely

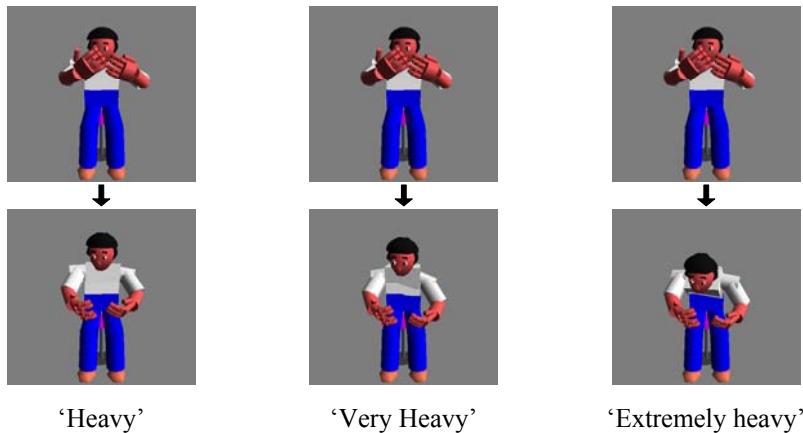
Since Japanese adverbs are quite vague and impossible to order, subjects are asked to reorder the adverbs on his/her own understandings during the test.

Table 3 shows the relations between emphasis level and parameter to give sign animation. Here,  $R$  is the ratio obtained by previous experiment explained in 3.1.

**Table 3. Parameter of Each Degree Adverb.**

	slightly	a little	(original)	very	extremely
Multiplication Parameters	$I/R^2$	$I/R$	1	$R$	$R^2$

Four kinds of modifier representation, which have different degree, were produced about each adjective. Three expressions are selected at random from 5 animations including original one. These animations are represented to the same subjects. Fig. 4 shows an example of selected animation.



**Figure 4. Automatic Generation of Modifier Representation.**

#### [Steps]

1. Three sign animations were represented concurrently to subjects.
2. Subjects connect a degree adverb and each animation with lines in questionnaire (Question 1).
3. After representing all animations, degree adverb is sequenced by subjects (Question 2).

Using a result of question 2, degree of adverb is averaged respectively. Order differs greatly in individuals and there are six patterns.

Experimental results clear that modifier representation is distinguished nicely. Thus, it is possible to produce many expressions by varying some parameters. The subjects couldn’t distinguish the degree of word ‘fast’. We carried out measurement of the word ‘fast’, ‘very fast’ and ‘extremely fast’ to find the reason of this result. As a consequence, it become clear that modifier representation of ‘fast’ doesn’t change gradually. ‘Very fast’ is expressed by smaller range and fewer frames than ‘fast’. And ‘extremely fast’ is expressed by smaller range and fewer frames than ‘very fast’ in proposed method. Whereas, ‘extremely fast’ is expressed by bigger range and fewer frames than ‘very fast’ in JSL. This is a reason why ‘fast’ cannot be distinguished correctly. It becomes clear that parameters of emphasis on “Range” and “Speed” needed to be changed separately to express various degree adverbs in some words.

### 3.3 Discussion

Experimental results make clear that the proposed method can generate more natural and legible sign animations, which express nuances of original sentences. Therefore the proposed method achieved a part of objectives of this research. However, some of the produced animations are still not fully satisfactory. The reason is that generated animation cannot express non-linear changes of motion speed according to modulation. As a result of data analysis, it found that it is necessary to consider the amount of a change in a time target to represent the modulation more naturally. Fig. 5 shows an example of data analysis.

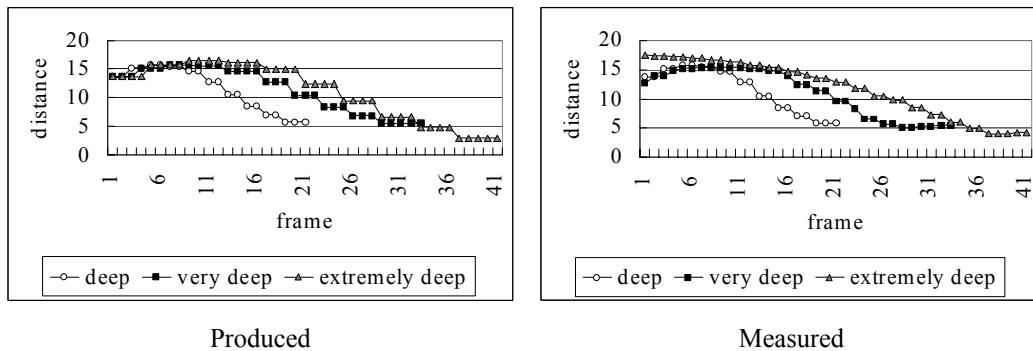


Figure 5. Analysis Result of Sign Animation 'Deep'.

In the next step, a method to express hourly change with a few parameters must be examined. Moreover, we must work on analysis about "Frequency" and consider direction information.

## 4. CONCLUSIONS

This paper proposes a method to include modifier representation into Japanese-JSL translation system, to improve legibility of sign animation. The analytical results indicate that modifier representation can be divided into some patterns. Based on an observation, modifier representation is classified into three features, "Range", "Speed" and "Frequency". The proposed method produces sign animation by varying these features and introducing several grammatical rules. Moreover, experiment results show that the proposed system can generate sign animation, which convey modifier representation. Additionally, the proposed system can generate various modifier representations.

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# Electronic usage of BLISS symbols

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## ABSTRACT

The desire for communication is every human being's own. It lives in people's mind whose own body deprives themselves of the possibility of relations between people. In the last few decades it was realized that not only the number of people who were kept alive is important, but also their quality of life. One of the base of the prosperities is the ability to adapting themselves to the community.

Two different software was made for partially disabled people, using these programs they are able to tell what one has got to say in the easiest and quickest way to their teachers or others, where the point can be a simple conversation, or writing a letter or just a composition. Both application use Blissymbolics, an alternative graphic symbol system that individuals with severe speech and physical impairments find much easier to learn and use than traditional print. First, a Bliss symbols sentence builder serves as a tool for boarders to compose and print Bliss symbol sentences. Second, at the age of the Internet an e-mail reader and writer software was designed especially for Hungarian BLISS users, while the format of the e-mail is compatible with the applications used in international practice.

## 1. INTRODUCTION

### 1.1 People with disabilities

Being different it's not too easy: the common experiences, actions, emotions are the things which attach the person to the group. The person who is left out from the common experience will be dragged into the edge of the society. One's isolation produces destructive effect on it's sentimental, social and mental life. The communication is not only the key for the entrance into the society, it is also the connecting power of the community. From the beginning, whose communication possibilities are limited compete with huge disadvantage in the war of prosperity. Our main task was making software for partially disabled people who can communicate hardly with others. The point can be a simple conversation or writing a letter or just a composition. As an alternate language, we use the BLISS symbols.

### 1.2 Bliss symbols

The creator of the Bliss language is Charles Kasiel Bliss. He was born in 1897 in the Austro-Hungary, Czernovitz and died in 1985 in Sydney. The Chinese pictograph symbols made a big impression on him. Bliss worked on a universal logic language. He ended his book *Semantography* in 1949 and felt to accomplish the dream of Leibniz, the creation of a mathematic clean universal language, independent of age, sex, intelligence and native language. His work was not accredited until 1971 when a workgroup in Toronto discovered it. Since then, an international Institute has built on the Bliss symbols.

At this time, the full dictionary has above 2000 symbols. All the symbols are based on basic graphical elements (Fig. 1) and on the combination of three different sizes. There are three shapes which appear only in one size. The basis of the symbols is the symbol square i.e. the basis of size comparison for the symbols inside one symbol set.

In the Bliss language there are about a hundred basic symbols which cannot be split into independent smaller units. The complex symbols stand for two or more basic symbols.

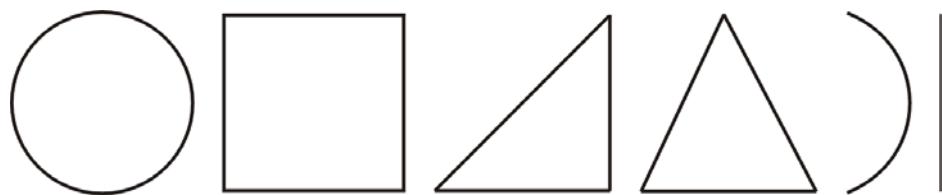


Figure 1. Basic Bliss elements.

## 2. BLISS SYMBOLS SENTENCE BUILDER

### 2.1 Look and use of the Bliss symbols sentence builder

The task of the Bliss symbols sentence builder is to serve as a tool for boarders to compose and print Bliss symbol sentences. The interface had to be designed for simple and easy use. The control had to be as simple as possible with the help of labeled buttons and their arrangement. Input can be done by the aid of buttons.

The Bliss symbol sentence with empty squares is at the bottom. Chosen symbols appear in this squares from the left to the right. Above the sentence there are function keys that implement paging, category switch and erase. For certain functions, a teachers authority is indispensable. Such a function is printing for example.

The Bliss symbols of the current category, divided into ten part sets, are above the function keys.

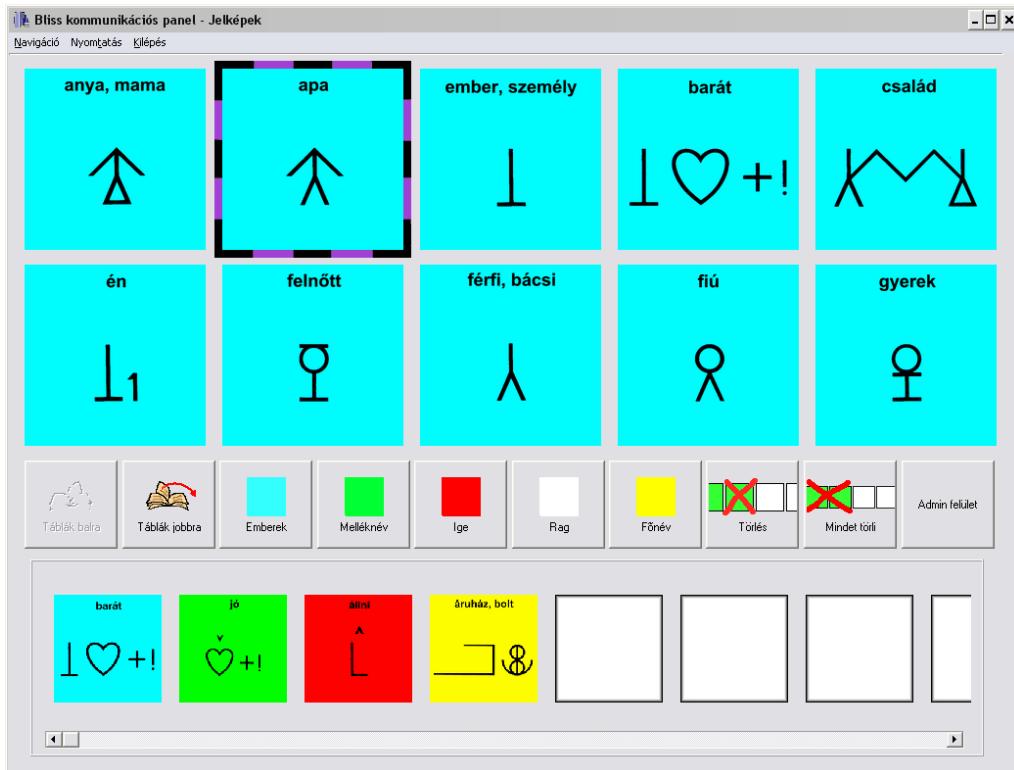


Figure 2. Bliss symbols sentence builder interface.

Different categories are marked with conventional different background colors. The categories are marked in the menu also with this colors. Above the symbols is a menu with functions meant for the advanced users or teachers. The navigation can be set here for the sentence builder. One can navigate among the function buttons by three ways. One way is to navigate with the cursor keys and the *enter* and *space* buttons. For the most advanced user, there is a way to navigate with the mouse. For the less advanced user, the third navigation method is implemented, the automatic movement. This means, the colored frame which marks the

actual active control is moved by certain time on a certain order among the buttons automatically. If the active control is preferred, the user has to press a switch. This can be any button of the keyboard but also a special input device, for example an external switch of the special keyboard of Intellikeys.



Figure 3. Intellikeys keyboard and external switch.

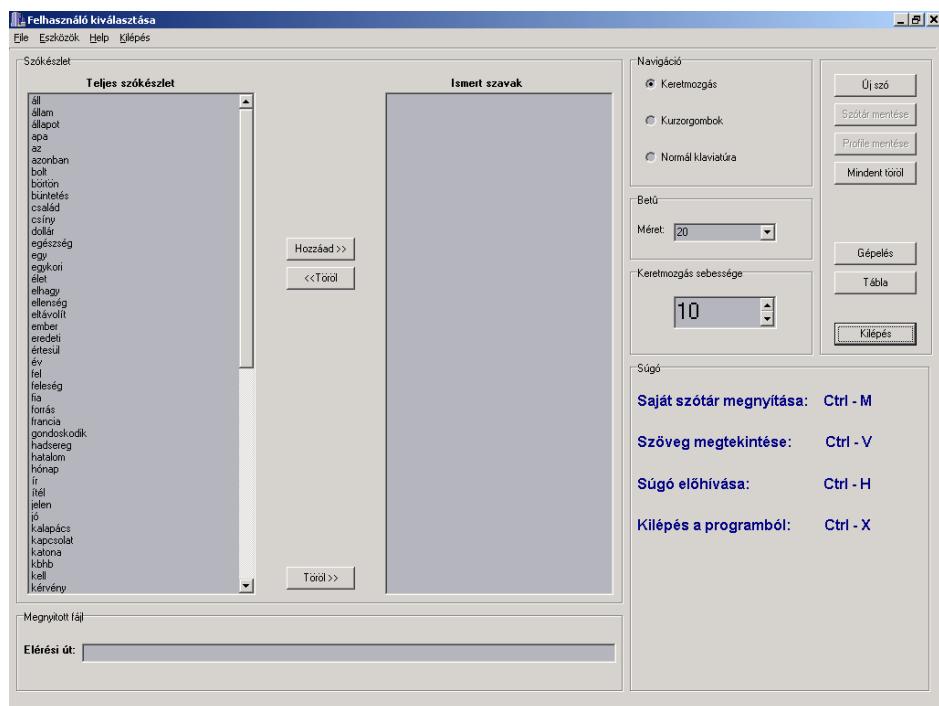


Figure 4. Picture from the Administrator interface

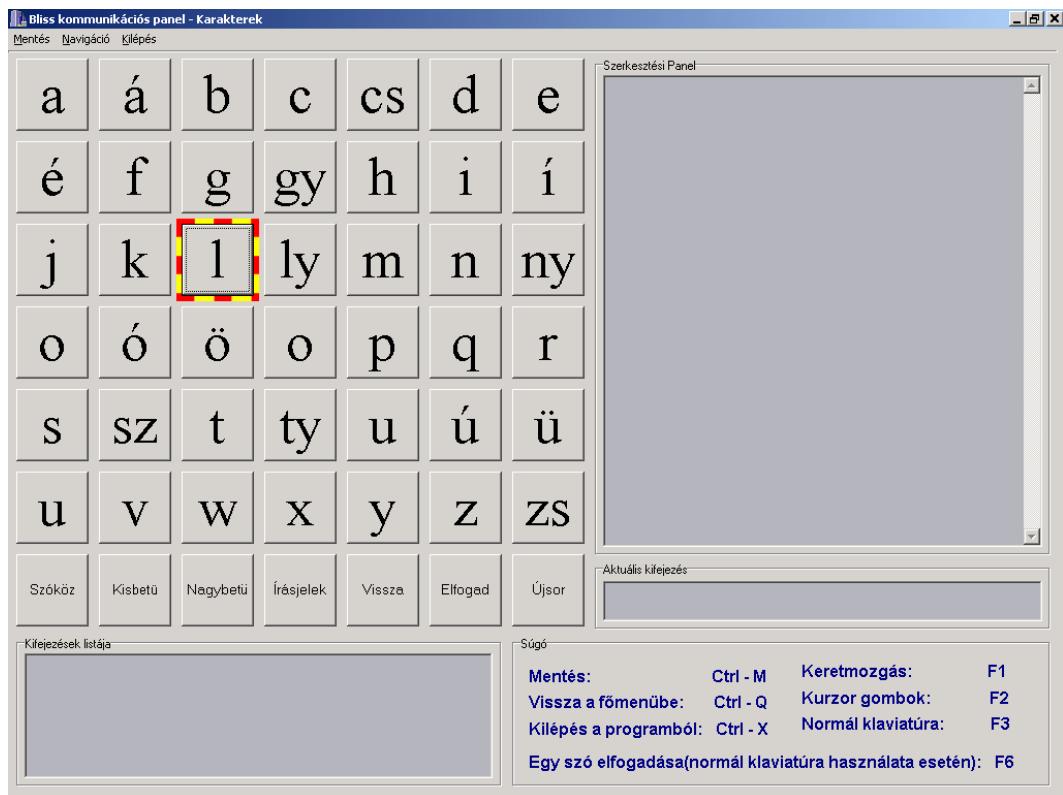
### 3. ADMINISTRATOR AND SENTENCE EDITOR INTERFACE

There is a main dictionary , part of the program, which could contain all the words that people can use. Before somebody first start using the software the teacher has to make the users own reduced vocabulary selecting the known words from the list box of the main dictionary. Certainly there is the possibility to add or remove words from both the main and the individual word stocks.

In case of the degree of the disorder the teacher can choose from three types of navigation: “moving frame”, control by cursors, or control by keyboard.

It is necessary to set the speed of the motion to the actual user, and to set the size of the letter using in the word processor due to the users disturbance of vision.

After all the settings were made, the teacher can switch to the editor interface and let the disabled to work.



**Figure 5.** Picture from the Sentence Editor interface

There are three well-separated parts of this screen. The letters of the Hungarian alphabet is located on the left side of the screen, each represented by a single button. Over the alphabet, other functions are needed for word processing, so seven function buttons: space, small letter, capital, punctuation marks, delete, accept, new line were added. Next to the 7x7 button matrix stands the text editor panel, which contains the typed document, and under the matrix the “matched expression” list is located.

Depending on the navigation type, the user can edit text in three different ways.

The type “moving frame” means, that a frame moves around the alphabet and the function buttons button by button and pressing only one key on the keyboard, e.g. Enter, the actual button took the represented action. Typing the first letter of a word the program starts matching it with the individual dictionary and list the found words into the “matched expression” list box. Typing more and more letters the number of the matched words decrease until only one remains and usually this is the word that the disabled wanted to use. Than he/she waits until the frame reaches the “accept” button and pressing the Enter key the whole word with the remaining letters will be inserted to the editor panel.

With this search function it is reached that disabled persons can type a whole word and whole sentences by pressing only one button, e.g.: Enter only a few times.

Depending on the degree of disorder, other two navigation types can be chosen. Control with cursors means that the moving frame is deactivated and the user moves it by the cursors, because he/she is able to use more buttons, not just only one. If somebody can use almost the whole keyboard, the control by keyboard navigation type can be chosen. It means that the focus stands on the text editor panel and the disabled uses the keyboards keys typing a text while the search function is still working and with a function key F6, he/she can accept a matching word, insert it into the text editor.

After the document is ready, the teacher can save it to Rich Text Format to archive the students work, so it can be possible to follow the development of each person. Certainly it is possible to open a previously saved document by the program in the administrator interface choosing the open command.

All the functions, like saving the text, changing the navigation, back to the admin interface, etc. can be activated by hot-keys, helping the teachers job.

## 4. BLISS E-MAIL FOR HUNGARIAN USERS

### 4.1 Blissymbol communication over the Internet

Various kinds of internet based supports for those who wish the use Blissymbolics were developed in the past. The development of BlissInternet (Blissymbolics Communication International, 1996) has lead to collaborative work with other developers, and a group of compatible software raised:

- BlissWrite - BlissInternet (Canada)
- WinBliss - SymbolMail (by Foreningen, Furuboda, Sweden)
- Bliss for Windows - Document Maker (by Handicom, the Netherlands)

These programs are currently under Beta test with field trials involving adult Bliss users in Sweden, the Netherlands, and Canada. The key of the effectiveness of these software is that the program does not send the picture of the symbols in the e-mail, only a code number which is defined by International Standards Organization (ISO). The advantage of the ISO coding approach is that much less data has to be sent. That's why the size of the letters is very economical, around few kilobytes. Fast communication came true via dial-up networking, furthermore the storage of the messages does not require big capacity. The hardware requirements are very poor as well, today operation systems require much more. The disadvantage is that you do need to have a program that can access or produce the Blissymbols from the ISO codes on each end.

There is one other email program that uses Blissymbols called Mind Express. It was created in Belgium but is not compatible with the others. The reason is that it converts the Blissymbols onto bitmaps and sends the bitmaps. All of the other programs expect the ISO code and can't read the bitmapped version although regular e-mail programs of course can.

The aim was to design an Internet standard based e-mail reader and writer software especially for Hungarian Bliss symbol users to be able to communicate with Bliss symbols users all around the world via e-mail. The ISO coding approach enables the communication between Bliss users of different countries, so the decision was made to make it possible for Hungarian Bliss users to join the above virtual community.

### 4.2 Bliss users in Hungary

In Hungary 0.4-0.6% of the population, 50-60.000 people have severe speech and physical impairments. In 1984 (for the first time in Central-Eastern Europe) a development program has started for children and young people with severe speech disorders and physical disabilities. In January 1987, Hungarian Bliss Center was founded, and Blissymbols were applied in the framework of complex rehabilitation services.

### 4.3 The development of the e-mail application

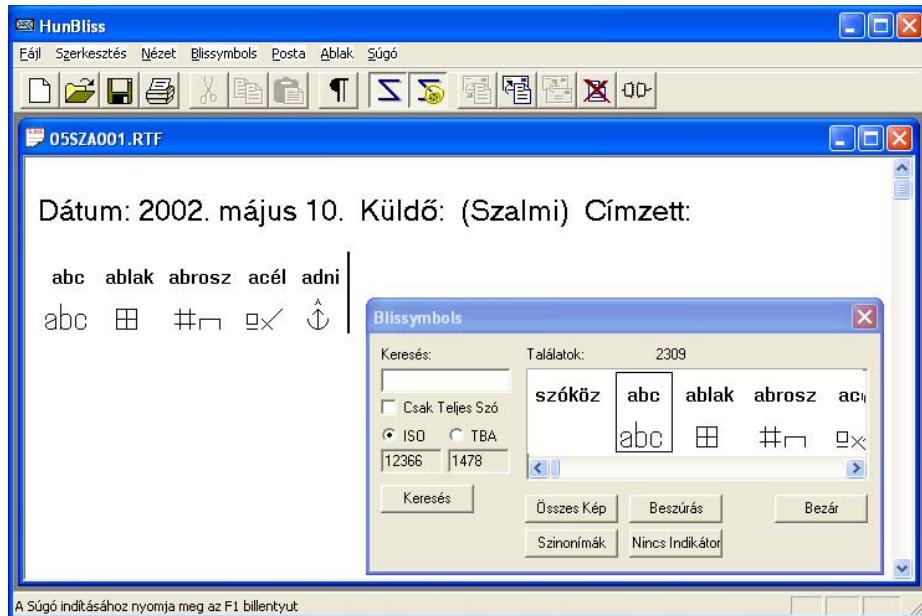
The Hungarian e-mail software follows the guidance of BlissInternet, which was the first application that widely allowed independence for Bliss users in the communication process, because Bliss messages could be sent via Internet to other users without the need of assistance. But, the disadvantage is that no domestic vendor was appointed, and finally just an English version is available.

The first step was the translation of the database provided by BCI (Blissymbolics Communication International). This database supported only standard English characters, was not compatible with Hungarian special national characters with accents (á, é, í, ó, ö, ő, ú, ü, ű). The standard ASCII (American Standard Code for Information Interchange) character coding had been replaced by extended ASCII (8-bit) coding. This change allows the use of the special characters of other languages as well, such as French.

At its core, the software is designed to serve three basic functions:

- First, it is a very economical way for non-speaking individuals to create their own messages in Bliss for any written communications task.
- Second, when combined with the services of an internet service provider, it provides a straightforward way for Bliss users to interact with others around the world who "speak" Bliss, regardless of their native tongue. It has a simple command for sending Bliss messages via email and the internet to anyone in the world who has an email address.
- Finally, it provides a flexible method for people who are working with Bliss users such as teachers, parents and clinicians who may not be fully conversant with the Blissymbolic language to create and interpret messages in Bliss. Thus the program is useful both for the person who has profound physical

disabilities and who cannot speak as well as for the various significant others who are working with that person.



**Figure 6. Picture from the e-mail application**

The input to the simple editor is text. Each entered word is matched against a lexicon database. If a match is found the corresponding symbol is displayed in the editor, otherwise the text is displayed. Symbols can be selected from a list, and can be retrieved by typing the ISO or the TBA code as well.

Third-party, keyboard scanning protocols and alternative access software can be also used for this application such as WiViK keyboard, SAW (Switch Access for Windows), Clicker3-4 (from Crick Software). These programs allow us the possibility to build hierarchical on-screen symbol chart systems, with which the user can select their symbols. On the other hand, external input devices can be also used such as definable membrane keyboards.

The disadvantage is that you do need to have a program that can access or produce the Blissymbols from the ISO codes on each end.

#### 4.4 Increase the usability – Grouping Blissymbols

The database contains 2304 symbols. It is very difficult to handle large number of symbols, that's why symbols are grouped into different categories. The software supports grammatical categories, word-classes (noun, verb, adjective) and the symbols are categorized by the meaning as well (Family, Animals...).

#### 4.5 Future improvements

The application of MS SAPI compatible speech synthesis or link wave files to have auditory support.

To develop a software that manages Bliss symbols and database of many different language, and do translation by the ISO codes.

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# Real-time clarification of esophageal speech using a comb filter

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## ABSTRACT

The only treatment for the terminal symptoms of the laryngeal cancer is to remove the larynx including vocal cords, which mean that the patient loses his voice. Esophageal speech is a method of speech production using an esophagus. An air inhaled in the upper esophagus generates the esophagus vibration to produce a belch-like sound that can be shaped into speech. Although this method has difficulties to be mastered, the voice is able to keep the individuality since the speech is generated by his own vocal organs. This paper introduces a software filtering algorithm which clarifies esophageal speech with the individuality preserved, together with user's evaluations by questionnaires.

## 1. INTRODUCTION

Although almost all the animals have voices, only human beings are able to employ speech to make verbal communication. The vocal sound is produced by the relevant operations of the vocal organs such as a lung, trachea, vocal cords, vocal tract, tongue and muscles. The airflow from the lung causes a vocal cord vibration to generate a source sound, then the glottal wave is led to the vocal tract, which works as a sound filter as to form the spectrum envelope of a specific voice. If any part of the vocal organs is injured or disabled, we may be involved in the impediment in the vocalization and, in case of the worst, we may lose our voices.

Over 20,000 patients are currently suffered from laryngeal cancer in Japan, and the only treatment for the terminal symptoms is to remove the larynx including vocal cords, which means that the patient loses his voice. Losing voice causes various difficulties in the communication with other people, since the employment of a voice is essentially important for us to make verbal communication.

Incidentally there are mainly two ways to recover voice. One is to use an artificial larynx, which is also called an electrolarynx and is a hand-held device with a pulse generator that produces a vocal cord-like vibration. The electrolarynx has a vibrating plastic diaphragm, which is placed against the neck during the speech. The vibration of the diaphragm generates a source sound in the throat, and the speaker then articulates with the tongue, palate, throat and lips as usual. The other is to learn esophageal speech, which is a method of speech production using an esophagus (Sato, 1993; Max *et al.*, 1996). In the speech air is inhaled and caught in the upper esophagus instead of being swallowed, and then the released air generates the esophagus vibration to produce a "belch-like" sound that can be shaped into speech.

The former has an advantage to be used by just being held to the neck and to be easily mastered, but the sound quality is rather electronic and artificial. Furthermore one hand is occupied to hold the device during the speech, which disturbs the gestural communication. On the other hand, the latter method has difficulties to be mastered (several years are ordinary required for the practice), but the voice is able to keep the speaker's individuality since the speech is generated by his own vocal organs, although several distinctive characters exist. Moreover the body parts such as hands and facial expressions are freely and actively used for the communication to assist the speech. Mastering the esophageal speech requires repetitious training, and the progress is slow and is hard to be recognized by the patient himself.

This paper introduces a real-time software filtering algorithm which clarifies esophageal speech with the individuality preserved, and presents the results of a listening experiment to evaluate the filtering ability.

## **2. BACKGROUND OF THE STUDIES CONCERNING THE ESOPHAGEAL SPEECH**

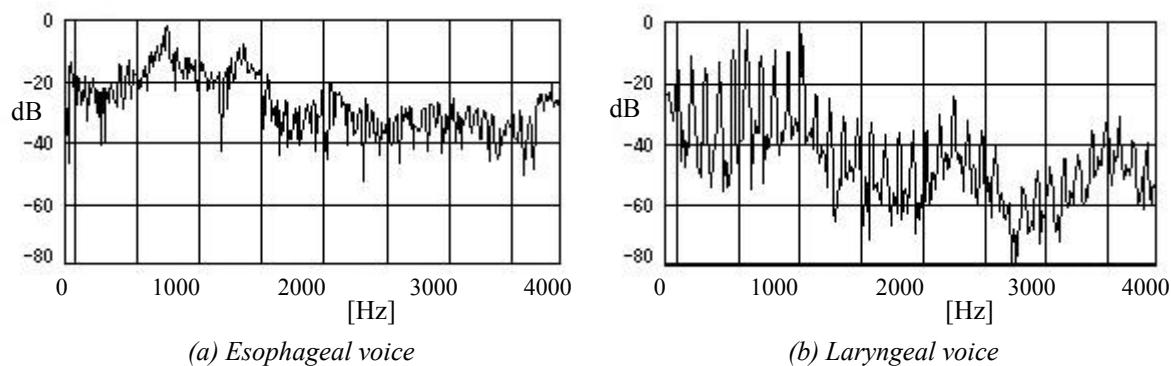
Several researches which analyze the characteristics of the esophageal speech have been reported so far (Noguchi & Matsui, 1996; Doi *et al.*, 1996), and a device to improve the esophageal voice is now commercially available (e.g. VivaVoice by Ashida Sound Co., Ltd.). The device is a package of a small circuit board equipped with a compact microphone and speaker, and transforms an unclear voice into clear by using the formant synthesis techniques, which has the disadvantage in keeping the individuality in the voices. Acoustic characteristics of the esophageal voice have been also studied (Lu *et al.*, 1997; Bellandese *et al.*, 2001; Robbins *et al.*, 1984), and have accounted for the lack of the phonetic clarity. There still remain unknown characteristics and features in the esophageal voices, however, the clarification theory and algorithm are not yet established.

### **3. PURPOSE OF THE STUDY**

An example of the spectrum of esophageal voice is shown in Figure 1 with the comparison of the normal laryngeal vocalization. Typical esophageal speech is characterized as below.

- 1) The voice contains noises caused by the irregular vibrations of esophagus.
- 2) Fundamental frequency is rather low.
- 3) Fundamental frequency and its overtone structure are not clear.
- 4) Fluctuation exists, which causes the instability of the voice.
- 5) Spectrum envelope is flatter than the laryngeal voice.
- 6) Volume is low because of the shortage of the expiration. (Average is 150 ml; laryngeal voice is 2000ml)

By considering the features mentioned above, we constructed a software algorithm by controlling a digital comb filter, which was considered to be applied effectively to control the noises and overtone structures for the clarification of the esophageal speech in real time.



**Figure 1.** Spectrum of Japanese vowel “a”.

## 4. FILTERING ALGORITHM

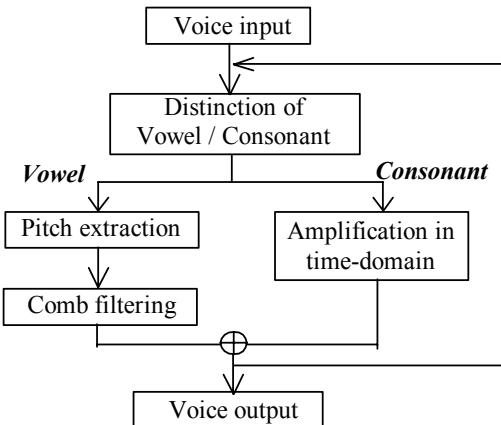
The filtering system is realized by using Max/Msp programming environment (Roads, 1996) on Macintosh Power Book (Power PC, 400 MHz) equipped with a microphone and a speaker. Sampling frequency was set to 44.1kHz with 16bits input. We paid attention to the characteristics 1), 3), 4) and 5), and applied the comb filter for the clarification.

Figure 2 shows the flow diagram of the filtering process. First the input signal is judged to distinguish vowels and consonants, and is divided into two procedures. For the vowel sound, fundamental frequency is extracted to form a comb filter as to enhance pitch components. The consonant sound, on the other hand, is enhanced in the time domain by multiplying its amplitude by a suitable coefficient. The calculations above are processed in realtime for every input to generate clarified speech outputs.

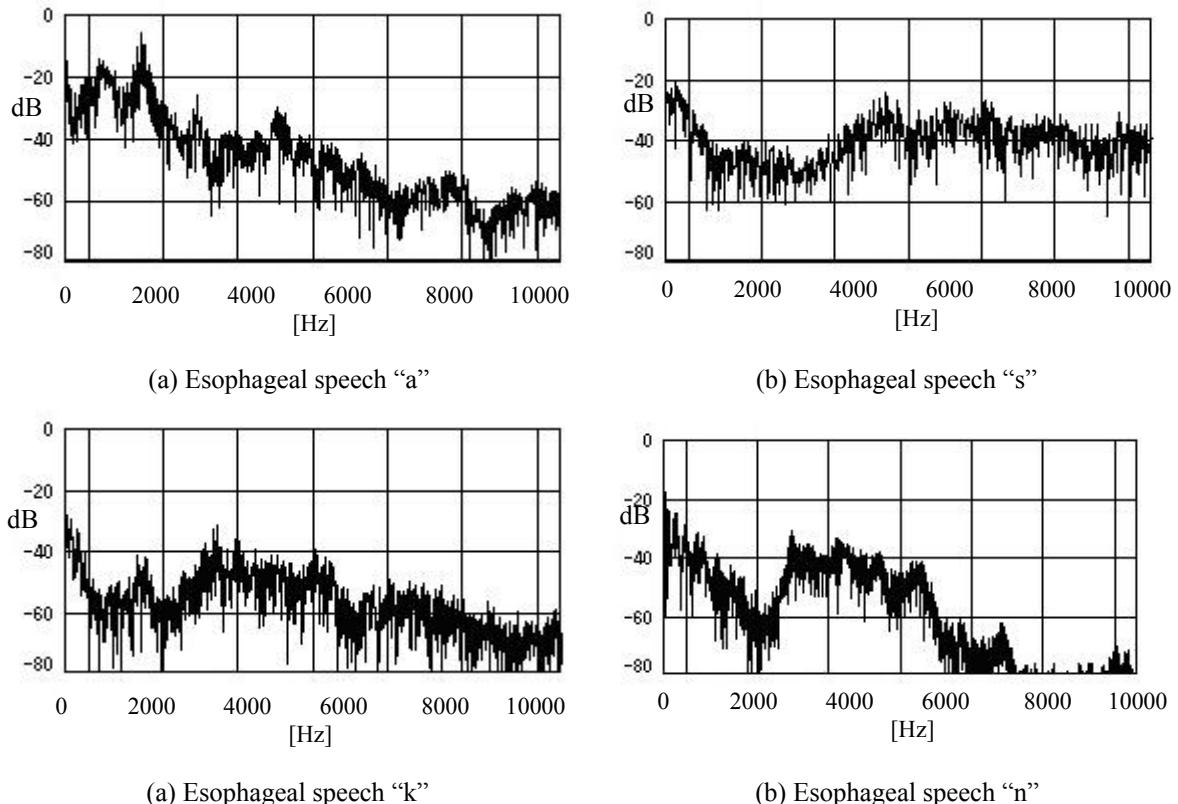
#### 4.1 Distinction between vowels and consonants

Comb filter is able to enhance pitch components. It means the filter affects opposite effect for the consonants

which can often be approximated as noise components. Since the consonant sound basically doesn't have the overtone structure, the comb filtering performs inadequately. Because of the different characteristics of sound phonemes to be clarified, vowels and consonants were required to be classified in advance to employ the different filtering techniques. We paid attention to the differences of the spectrum envelope observed in the frequency domain, and have proposed a filter to distinguish with each other.



**Figure 2.** Flow diagram of filtering



**Figure 3.** Comparison of vowel and consonant.

Figure 3 shows the power spectra of a Japanese vowel "a" and consonants "s", "k" and "n" for the comparison of each characteristics. Since the spectrum of the consonant is broadly distributed in the frequency range, the power spectra are presented by 10kHz in the figures.

Notable differences were found between the two spectra. The spectrum envelope of the vowel sound shows a couple of peaks in the lower frequency range, which are characterized as the formants, and the power gradually decreases as the frequency rises. The consonant sounds, on the other hand, are characterized as noises, and their spectra are uniformly distributed along the frequency range without a specific peak. The above observations justify the assumption that vowels and consonants can be separated by comparing the power balance between the low frequency range and the high frequency range. We defined an index as

$$B_{index} = \frac{\text{Average power of low frequency range}}{\text{Average power of high frequency range}}$$

where the low frequency range was set to 200Hz ~ 4kHz and the high frequency range was 6kHz ~ 10kHz. For vowel sounds, the index value becomes larger because of the concentration of the power in the lower frequency range, on the other hand, the value becomes around 1 for consonant sounds. The threshold for the distinction was set to 1.5 by the experiment, which was not influenced by the amplitude of the input signal.

#### 4.2 Experiment of distinction between vowels and consonants

We conducted an experiment of the separation of vowels from consonants by using the method mentioned above. Table 1 shows the result, in which 1 and 0 represent the recognition results of the vowels and the consonants respectively.

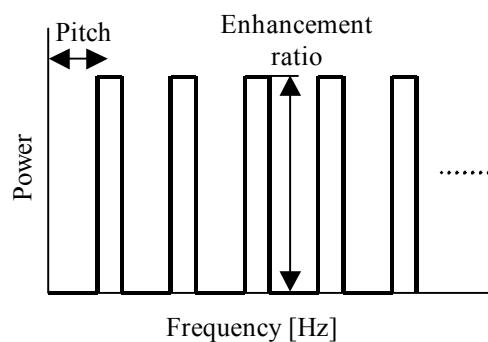
In the experiment, the algorithm could output correct answers for all the fricative and plosive consonants such as “k”, “s”, “p” and “t”, which are regarded as the voiceless consonants. The other consonants like “n”, “m” and “r” were, however, sometimes mis-recognized as vowels, since these sounds are categorized as voiced consonants which attend the vocal cord vibration. Fundamental frequency exists, though it is almost indistinct, and the negative effects of the comb filter were not found in the filtering of the voiced consonants. In this experiment, the mis-recognitions for the voiced consonants were overlooked.

**Table 1.** Result of vowel/consonant separation (1: vowel, 0: consonant)

s	a	s	i	n	a	n	i
0000000	11111111	000000	11111111	010111	11111111	11111	111111111
k	a	k	i	m	a	m	i
00000	111111111	00000	111111111	011111	111111111	001111	11111111111
t	a	t	i	r	a	r	i
00000	11111111	000000	111111111	0011111	111111111	1111111	1111111111

#### 4.3 Comb filtering

As obviously comprehended by Figure 4 which shows the impulse response of the comb filter, the overtone structure of a comb filter enhances a fundamental frequency and its harmony components. By suitably operating comb filters, esophageal voices can be clarified with their overtone structure enhanced and their noise components controlled. The importance is to extract the fundamental frequency precisely. In this system we adopted a short time zero-cross method for the pitch calculation. The extracted pitch works to form a comb filter with its pitch span and enhancement ratio suitably defined. The individuality of a speaker can be also preserved, since the comb filter enhances the overtones without changing the formants and the spectrum envelope.

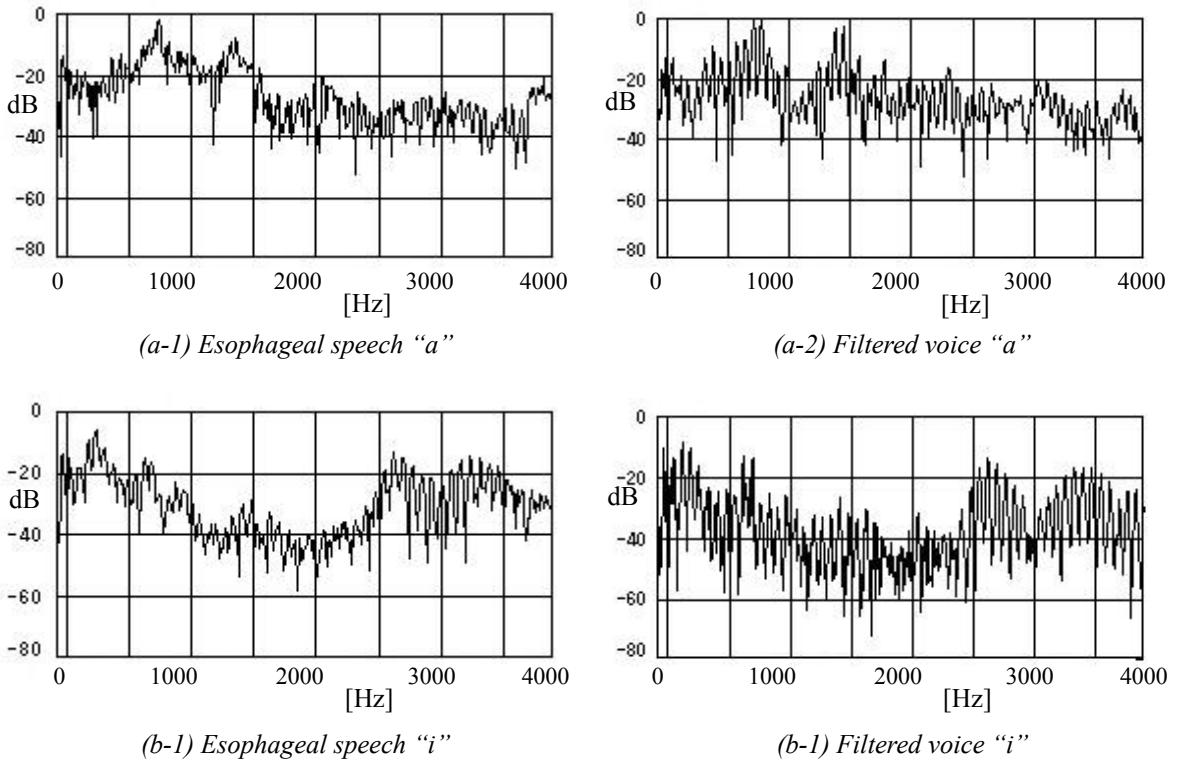


**Figure 4.** Impulse response of a comb filter

#### 4.4 Experiment of comb filtering for vowels

We conducted an experiment of the filtering for esophageal vowels. Figure 5 shows the power spectra of esophageal speech “a” and “i” before and after the filtering.

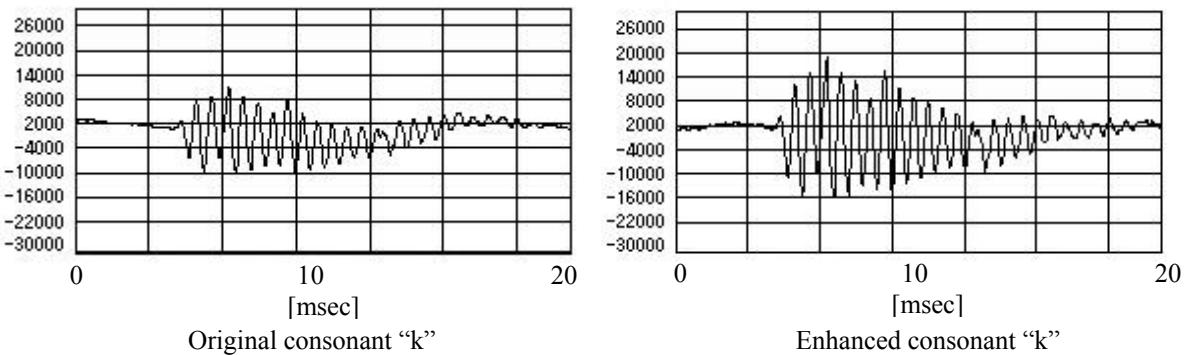
The proposed filter could form the clear overtone structures of the fundamental frequencies. The spectrum envelope was preserved throughout the frequency range, and the peaks and valleys of the overtones were enhanced, which contributed to the noise reduction. The individuality of the speaker was well preserved and the improvement of the clarification was also recognized.



**Figure 5.** Results of the comb filtering.

#### 4.5 Processing for the consonants

The volume of the esophageal speech is generally low because of the lack of the expiration pressure, and the consonant pronunciations are insufficient and difficult to be distinguished. The consonant sound is enhanced in the time domain by multiplying its amplitude by a suitable coefficient. Figure 6 shows the waveform of the enhanced consonant "k" with the original sound wave for the comparison.



**Figure 6.** Waveforms of consonant "k" before and after the filtering

By considering the characteristics of the esophageal speech described in the sections above, we constructed a real-time clarification filter in the Max/Msp programming environment as shown in Figure 7. The box (or block) in the program is called a graphical object, in which algorithms, computations or processes are described and stored by the programming language. By connecting graphical objects with lines, the filtering program can be built and executed.

To compare the filtered voice with the input esophageal speech, recorded voices are used for the listening experiment. The Max/Msp program shown in the Figure 7 opens a sound file at the beginning, and executes the filtering to output a voice from the speaker.

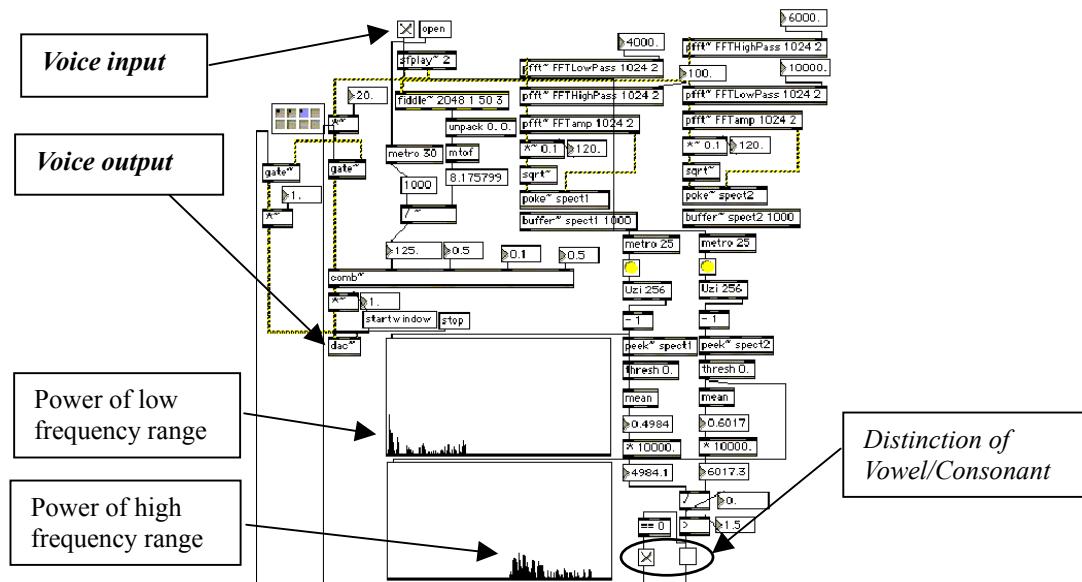


Figure 7. Clarification program of the esophageal speech

## 5. LISTENING EXPERIMENT

We conducted a listening experiment to evaluate the filtering ability by questionnaires. 11 able-bodied subjects listened to 12 pairs of unfiltered and filtered esophageal speech in random orders, and evaluated them in 5 levels from 11 points of view, which are

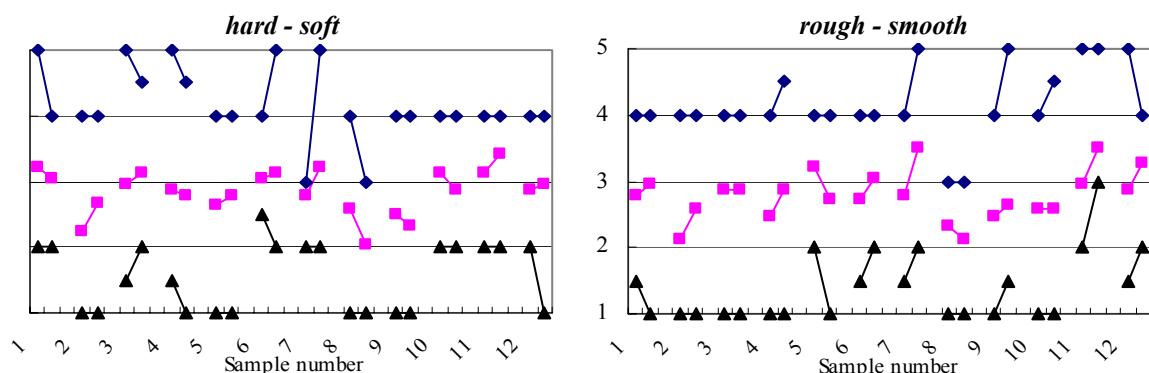
**hard-soft, rough-smooth, unclear-clear, blur-sharp, unpleasant-pleasant, electronic-human, noise level, echo level, clarification level of consonants, clarification level of vowels, and total evaluation.**

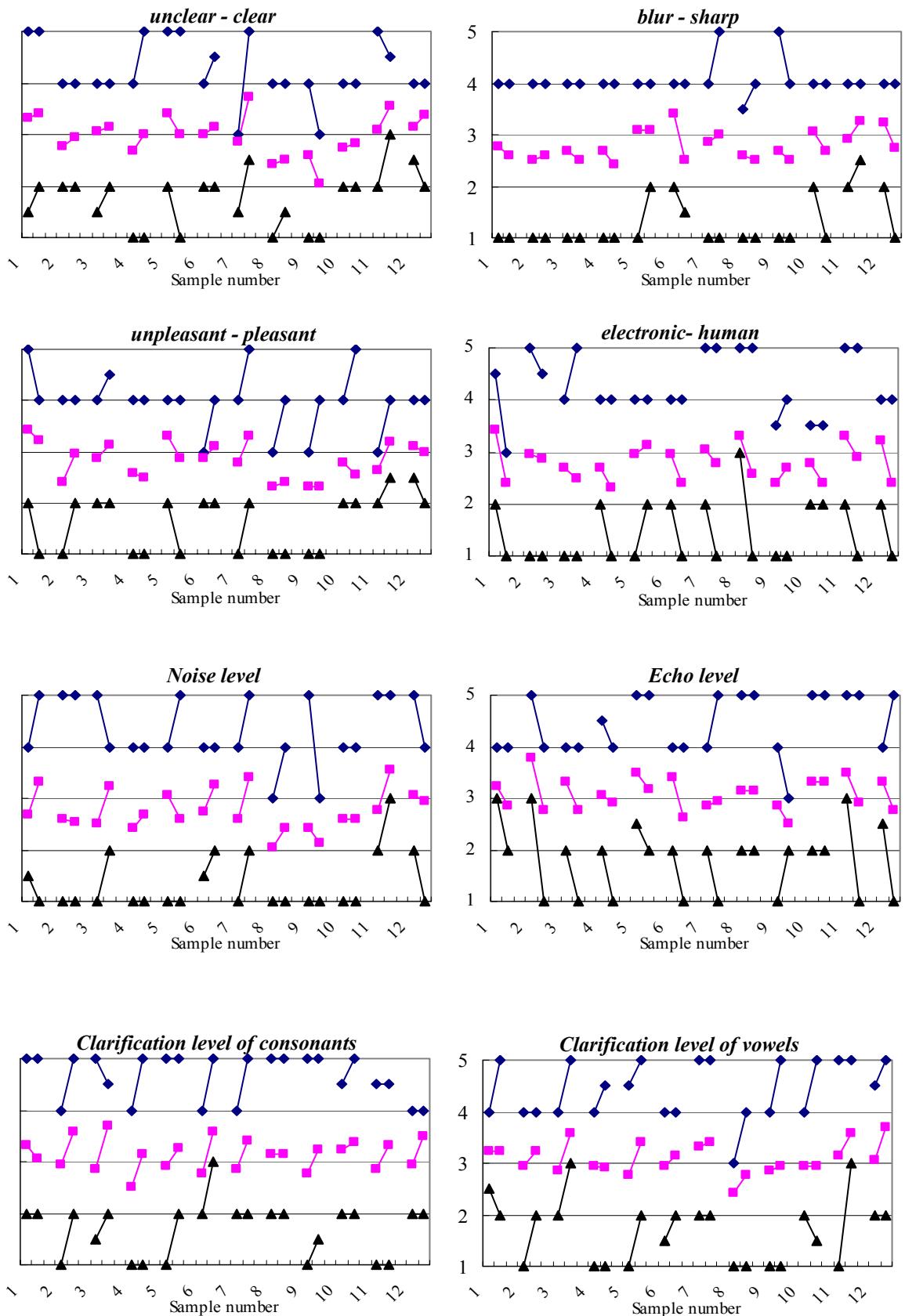
In the adjective pairs, the former was assigned as level 1 and the latter was rated as level 5, and the levels between 1 and 5 were rated according to the subject's evaluation. The larger the points are, the higher the filtering results were evaluated for the other evaluation points such as noise level and clarification level.

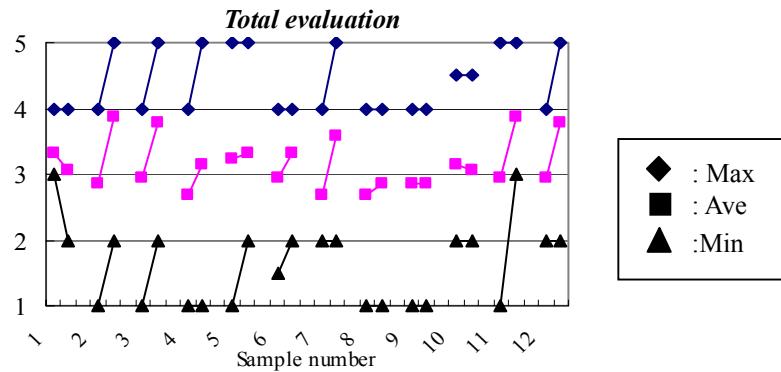
Figure 8 shows the results of the listening experiment, in which the maximum points are plotted with the mark  $\blacklozenge$ , the average points with  $\blacksquare$ , and minimum points with  $\blacktriangle$ . In the pair of each plot, the left one indicates the evaluation of the original speech and the right one gives the results of the filtering. If the right plot of a pair is higher, the filtering is considered to be effective.

In almost all points, the filtered voices achieved higher evaluations, especially in the points of smoothness, clearness and sharpness. In the evaluations of **noise level, clarification level of consonants, clarification level of vowels, and total evaluation**, better impression were obtained as expected by the consideration of effectiveness of the comb filters.

In the points of **hard-soft** and **unpleasant-pleasant**, on the other hand, obvious differences could not be found. A few subjects pointed out the unexpected echo effects and the electronic impressions, which could have been caused by the mis-detection of the pitch.







**Figure 8.** Results of listening experiment

## 6. CONCLUSIONS

This paper introduced a real-time software filtering algorithm which clarifies esophageal speech with the speaker's individuality preserved, and presented the results of the listening experiment to evaluate the filtering ability. The filtering results were preferably evaluated by the listeners in the points of the noise level and the clarification of vowels and consonants, as we had designed to complement the unclear factors and to enhance the clarity by considering the effectiveness of the comb filter. There still remain the problems such as the echo effects and electronic impressions caused by the mis-detection of the pitch. We continue to construct the precise filtering system to clarify the esophageal speech with the speakers individuality preserved, and examine the possibility to provide a portable device to generate the natural vocalization at any time and place.

We are currently working to expand the filtering algorithm to apply to the voice with the cerebral palsy. Since the voice has distinct characteristics which seem to be different from the esophageal speech, the different filtering techniques have to be examined. The software algorithm can be installed in a portable device to contribute to the use in mobile, and the study will support the verbal communication without being aware of the handicaps in speech.

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# **Distinctive training methods and evaluation of a multilingual, multimodal speech training system**

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## **ABSTRACT**

A multilingual, multimodal speech teaching and training system has been developed for 5-10 years old speech handicapped children, in the frame of the SPECO Project, funded by the EU (Contract no. 977126) in 1999. During the training the patients see the speech pictures of the reference speech and listen to the sound of it at the same time. Thus they use the human visual and auditory feedback during their speech learning beside the tactile sensation. A detailed evaluation examination was prepared at the end of the development of the system. Firstly the opinion of speech therapists from different educational field that had been using the SPECO system in their work for a longer period was collected and summarized. Secondly, an objective evaluation was organized to examine the efficiency of the system. It became clear from the objective experiment and from the collection of the opinion of the speech therapists, that the system is a useful and effective teaching aid.

## **1. INTRODUCTION**

Obviously, it is not a simple task to assess the effectiveness of a multimedia teaching system. There are some organizations, which give technique for the evaluation of multimedia teaching software [1, 2, 3]. For example the Evaluation Outline of TEEM [2] is very good, giving detailed questionnaires about the Installation, Content, Design and navigation, Easy of use, Special needs, Courseware etc. These questionnaires are very important, and the answers help the software development, but those are too general and usually concern the usage or outward appearance.

But how can we examine the effectiveness of a speech-training tool? For example how can we decide that the system developed in the frame of SPECO project is better or not, or more effective than the traditional one?

During the development of our system all SPECO partners were keeping close contact with speech therapists from different educational fields and asking them repeatedly for their opinion. We have constructed questionnaires too one is presented in Table 1.

These and similar questionnaires were filled out by the therapists from time to time. The answers gave us information about the occasional problems with the system and facilitated making corrections continuously. Thus the software and database became better and better.

## **2. SHORT DESCRIPTION OF THE SYSTEM**

The SPECO Project was founded by the EU through the INCO-COPERNICUS program (Contract no. 977126) in 1999. In the frame of the project a system has been developed which is an audio-visual pronunciation teaching and training tool for 5-10 years old children. Correction of disordered aspects of speech is progresses by real time visual presentation of the speech parameters, in a way that is understandable and interesting for young children, while remaining correct from the acoustic-phonetic point of view. The development of the speech by our teaching method progress mainly on the base of visual information using the intact visual channel of the hearing impaired child. However during practice we use their limited auditory channel too, by giving auditory information synchronised with the visual one. This multi modal training and

teaching system have been developed for the languages of all SPECO partners; these are English, Swedish, Slovenian and Hungarian [4, 5, 6, 7, 8].

The system is composed of two parts: one is a general language-independent frame program, the so-called Measuring System and Editor and the other is a Language Dependent Reference Database file. These two parts together make up the Teaching and Training Support, which is the program for users. Generally, the frame of the program gives possibility to construct the teaching and training support of any kind of languages using a well-defined database of the language. It measures the different acoustic-phonetic parameters of the speech signal, and helps the user to select the reference speech examples, to place the symbolic pictures and background pictures into their right places. It is possible to build a vocabulary with a special structure, according to the language.

**Table 1.** A questionnaire for the evaluation of SPECO project.

<i>Name:</i>
<i>Job:</i>
<i>How long have you been using the program?</i>
<i>How good do you find this method from pedagogical point of view?</i>
<i>Does the user manual give orientation enough?</i>
<i>Is special skill necessary to the usage of the program?</i>
<i>Is training a pleasure for the children?</i>
<i>Do children understand the feedback in the program?</i>
<i>Are pictures understandable in the exercises “isolated sound”?</i>
<i>Are the speech pictures understandable for children in the exercises of syllables, words and sentences?</i>
<i>Is more training possibility necessary during the exercises?</i>
<i>Is less training possibility enough during the exercises?</i>
<i>Would any other kind of training possibilities be useful?</i>
<i>If yes, which ones?</i>
<i>What is your opinion about the exercises?</i>
<i>Have exercises developed the speech of the children? In what?</i>
<i>Preparation:</i>
<i>Sound development:</i>
<i>Practice in sentences:</i>
<i>Intonation:</i>
<i>Was it difficult to work with the program? If yes, please explain.</i>
<i>How long did it take for a phoneme in isolation to form perfectly?</i>
<i>How long did it take for a phoneme in continuous speech to form perfectly?</i>
<i>What is the difference with traditional therapy?</i>
<i>Did you like this method?</i>
<i>Any other ideas?</i>

### 3. EVALUATION OF THE DISTINCTIVE TRAINING METHODS

The SPECO system is very flexible. Useful in many cases of speech defects, but the speech therapists must use it in a different way according to the defect. These are for example the different speech defects with normal hearing, with hearing impairment, etc. and in the special therapy of cochlear implants. different training methods have been developed and used in practice.

The SPECO System has been presented to the speech therapists from time to time, and asked for their opinion during the development. Two types of the evaluation were prepared: a qualitative and a quantitative one.

#### 3.1. Qualitative evaluation.

Qualitative evaluation was based on the answers of the therapists that worked with the SPECO System during three months or half a year. They filled in a special questionnaire.

In general, the therapists were very satisfied with this method of learning. The summarised opinion of the teachers in case of all languages was very good. The developed method of learning is very useful, especially as supplement and variegation to classical methods. It is a very welcome modification in the work, pleasant for children and useful in the therapy of many speech and hearing disturbances. The level of good usage depends on the therapists. From pedagogical point of view it is very highly rated.

### *3.2. Quantitative evaluation*

Quantitative evaluation was based on the comparison of the intelligibility development of the children trained by the SPECO program, and by the traditional method (control groups). We examined different speech handicapped groups.

#### *3.2.1. Trained pupils*

40 of 6 to 8 year old children were selected from 240 and grouped according to the degree of impairment. The groups (audiometric pre-examination have been made without hearing aid) were the followings:

- children with normal hearing (H),
- children with small hearing impairment (SMH),
- children with middle hearing impairment (MH),
- children with severally hearing impairment (SH),
- children in the control group, trained only by traditional method.

#### *3.2.2. Recording of the speech of pupils*

18 well-selected words were recorded pronounced by the pupils in 3 phases:

- 1<sup>st</sup> phase before the training in October 1999
- 2<sup>nd</sup> phase after the training in May 2000
- 3<sup>rd</sup> phase after the summer holiday in October 2000.

Comparing the recorded material of the 1<sup>st</sup> and the 2<sup>nd</sup> phases, the result gives information about the effectiveness of the SPECO method and about the quality of speech. Comparison of the speech of pupils in the phases 2 and 3 shows whether the pupils could stay or not at the level they had reached during the training.

#### *3.2.3. Listening test*

30 non-expert young people took part in the listening test on 28<sup>th</sup> of October 2000. Word pairs were composed from the same speakers for the same words recorded in different phases. The obtained pairs of 1-2, 1-3 and 2-3 were listened randomly. Listeners were asked to mark a decision about which words were more understandable in the word pairs. It was allowed to mark too if they could not make a decision.

#### *3.2.4. Result of the listening test*

The listening test gives clear results presented in Table 2. where the decisions of the listeners are given according to the groups.

In SPECO group in the Table we averaged the results obtained in those of 4 groups where teacher used the SPECO system through the training. In control group the teacher did not use any computer-based tools. In general in all groups the listeners found the words after the training much more understandable. More listeners found the intelligibility better in those groups at which the teacher used the SPECO system.

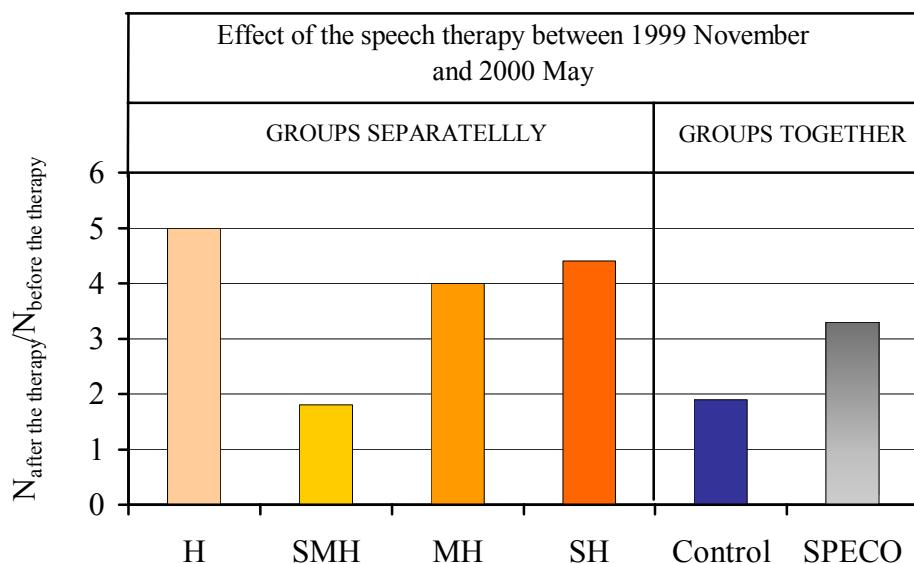
To see the effect of the speech therapy more exactly we examined the word pairs 1-2 separately, and compared the number of the decision to the second word (N after the therapy), with the number of the decision to the first one in the word pair. See the Fig. 1. The effect of the speech therapy is evident.

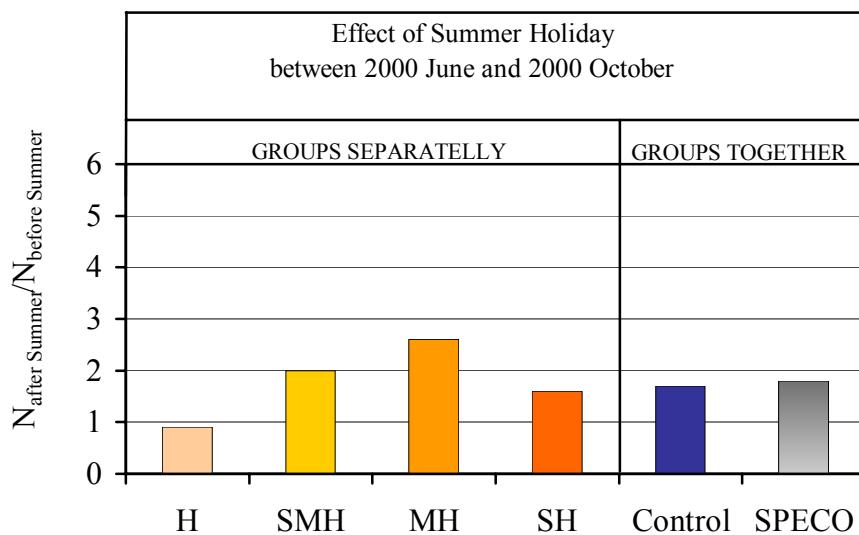
To see the effect of the summer Holiday we examined the word pairs 2-3 separately. To do this we compared the number of decisions for the second word (N after summer) with the number of the decisions of the first one (N before summer) in the word pairs. Children's speech developed during the summer too in all groups, as you can see in Fig. 2. It is quite natural why the age of 6-8 is the age of linguistic development at these severally impaired children. Here the speech development in the SPECO group and the control group is the same. The children could keep their knowledge, obtained during the therapy and they could develop further.

**Table 2.** The results of the listening test for the examination of the effectiveness.

		Decisions in the listening test		
Type of the groups	Pairs for listening	The FIRST word in the pairs is better [%]	The SECOND word in the pair is better [%]	Uncertain decision [%]
all groups together	1-2	18	55	26
	1-3	14	66	20
	2-3	22	40	39
control group	1-2	24	45	31
	1-3	14	58	28
	2-3	20	35	44
SPECO group	1-2	17	57	26
	1-3	14	67	19
	2-3	22	40	38
normal hearing (H)	1-2	15	74	11
	1-3	16	73	12
	2-3	24	22	54
small hearing impairment (SMH)	1-2	25	46	29
	1-3	21	64	14
	2-3	24	48	28
middle hearing impairment (MH)	1-2	16	62	22
	1-3	9	78	13
	2-3	20	52	27
severely hearing impairment (SH)	1-2	12	53	35
	1-3	12	57	31
	2-3	22	35	44

**Figure 1.** The effect of the speech therapy in the word pairs 1-2.





**Figure 2.** The effect of the summer holiday in the word pairs 2-3.

In SPECO groups the result is much better, than in control groups. Number of the decision in the case of SPECO groups is 1,7 times bigger. Comparing the groups with each other, the development of the children was the best with normal hearing. Then the severely hearing impaired children follow.

#### 4. CONCLUSION

The teachers gave a summarised opinion about the SPECO system. The general experiences of the teachers were the following:

1. Children can use this multimodal system by themselves very easily and they use it with pleasure, which is a very important factor from the point of view of efficiency.
2. The visual feedback helps children to see whether their pronunciation is correct or not, and how far it is from the correct one. They are not in need of relying only on the teacher's opinion. In particular, this is very important in case of speech handicapped with hearing loss.
3. In general, sounds were formed sooner, than in control groups where they do not use any computer-based teaching system.

It was found that a consistently shorter time was required for improving a speech sound than was the case with corresponding children of similar mental ability and impairment level who had been instructed by the traditional method. However, it is difficult to express the results in quantitative data because the result depended on many other factors (for example, one highly important factor was how much additional help the child received at home).

4. In those cases when these sounds were very resistant to the traditional therapy, the new method helped to repair these sounds.
5. The system is a useful tool for teachers in the individual linguistic training. It gives possibility to train in small groups too and pupils can use the system themselves and practice alone.

Of course, especially for young children the visual tool itself does not substitute the work of the speech therapist. On the first hand, this tool is a good aid. It helps the work of the therapist and gives a variety to teach. On the other hand, at the automation-phase or in case of elder children, the visual tool itself gives a good possibility to practice alone.

The objective measurement gives the following results:

1. The effectiveness of the SPECO system is essentially better than of the traditional one, with which the teachers do not use any computers or such a visual feedback.

2. After the training pupils can keep the level of their speech product reached by the SPECO system.

It is clear from the objective experiments and from the opinion of the speech therapists, that the system is an effective teaching aid.

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# ICDVRAT 2002

## Session III. Stroke Rehabilitation and Haptics I

Chair: Robin Morris



# **Immersion without encumbrance: adapting a virtual reality system for the rehabilitation of individuals with stroke and spinal cord injury**

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*[http://hw.haifa.ac.il/occupa/hebrew/cv/tamar\\_w.html](http://hw.haifa.ac.il/occupa/hebrew/cv/tamar_w.html)*

## **ABSTRACT**

The purpose of this paper is to present results describing the use of a projected, video-based VR system in neurological rehabilitation. The first part describes the adaptation of several of the VividGroup's Gesture Xtreme projected VR scenarios (control of the type, speed, location and direction of all stimuli) and documentation of all subjects' performance. The second part of paper presents initial results in which the system is being used in a clinical study with stroke patients who display symptoms of left unilateral neglect and other cognitive deficits, with those who require balance training as a result of complete or incomplete spinal cord injuries, and young, non-speaking adults who have cerebral palsy and moderate mental retardation.

## **1. INTRODUCTION**

Injury or disease to the central or peripheral nervous systems typically results in a decreased ability to perform activities of daily living, due to the resulting cognitive and motor deficits. An essential part of the rehabilitation process is remediation of these deficits in order to improve the functional ability of the patient, and to enable him or her to achieve greater independence. One of the major challenges facing therapists in neurological rehabilitation is identifying intervention tools that are effective, motivating, and enable transfer of the skills and abilities achieved during rehabilitation to function in the "real" world.

In recent years, virtual reality technologies have begun to be used as an assessment and treatment tool in rehabilitation (e.g., Brown et al., 1998; Christiansen et al., 1998; Grealy et al., 1999; Rose et al., 1999; Rizzo et al., 1997; Schultheis and Rizzo, 2001; Riva et al., 1999; Weiss et al., 2002; Linden et al., 2002). These first studies have yielded encouraging results that support the further exploration of VR as an intervention tool in rehabilitation (Schultheis and Rizzo, 2001). Positive attributes include its suitability for the objective measurement of motor and cognitive performance in settings that are safe, ecologically valid, may be delivered in a standardized protocol and may be tailored to each individual's functional level via precise gradation of stimuli.

The majority of VR rehabilitation applications have focused on the development of virtual environments, and demonstration of their reliability and feasibility. However, to date, its effectiveness as an intervention tool in neurological rehabilitation has been insufficiently explored, especially with the VR systems based on video projection. Moreover, some of the current studies use relatively expensive VR systems whose cost and technical complexity preclude their adoption in most clinical settings. There is also concern that use of immersive VR systems that rely on externally affixed devices (e.g., a head-mounted display) may cause disturbing side effects, particularly in patients who suffer from neurological deficits.

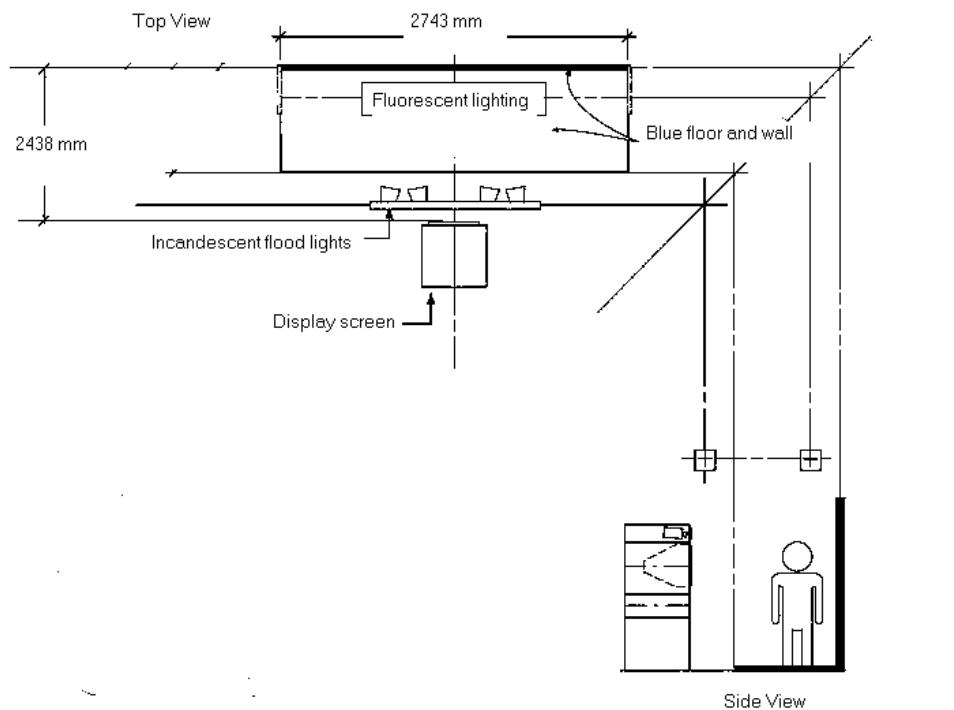
The purpose of this paper is to present results describing the use of a projected, video-based VR system for use in neurological rehabilitation. Our first objective is to present work carried out in our laboratory over

the past year that has resulted in the adaptation of several of the VividGroup's Gesture Xtreme projected VR scenarios such that it is now possible to completely control the type, speed, location and direction of all stimuli and to document subjects' performance. Our second objective is to present initial results of our currently ongoing research in which the system is being used in a clinical study with stroke patients who display symptoms of left unilateral neglect and other cognitive deficits, with those who require balance training as a result of complete or incomplete spinal cord injuries, and young, non-speaking adults who have cerebral palsy and moderate mental retardation.

## 2. VIVIDGROUP'S GESTURE XTREME VR SYSTEM

We have commenced a series of studies using VividGroup's Gesture Xtreme VR System, a unique approach to virtual reality, which has potentially important applications for the rehabilitation of children and adults with physical and/or cognitive impairment [[www.vividgroup.com](http://www.vividgroup.com)]. When using the Gesture Xtreme VR system, users stand or sit in a demarcated area viewing a large monitor or projected image that displays one of a series of simulated functional tasks, such as catching virtual balls or swimming in a virtual ocean (See Figure 1). A digital video camera converts the video signal of the user's movements for processing by unique software. The participant's image is processed on the same plane as screen animation, text, graphics, and sound, which react accordingly depending on his or her movement. This process is referred to as "video gesture", i.e., the initiation of changes in a virtual reality environment through video contact. The participant's live on-screen video image responds at exactly the same time to movements, lending an intensified degree of realism to the virtual reality experience. The result is a complete engagement of the user in the simulated task.

The Gesture Xtreme VR system was originally developed as an entertainment system, designed to demonstrate VR in science museums and popular expositions. It is only via adaptations complying with principles based on rehabilitation intervention principles that permit its use as an effective rehabilitation intervention tool.



**Figure 1.** Block diagram of Gesture Xtreme system (adapted from [http://www.vividgroup.com/techsupport/design\\_plans/gx100\\_page3.jpg](http://www.vividgroup.com/techsupport/design_plans/gx100_page3.jpg)).

The Gesture Xtreme VR system contains a number of virtual environments. In our studies we are initially using four of these environments, three of which we have adapted as an intervention tool:

- **Birds and Balls** - The user sees himself standing in a pastoral setting (Figure 2). Balls of different colors emerge from different locations and fly towards the user. Touching these balls with any part of the body causes them to turn into doves (if the touch is “gentle”) or to burst (if the touch is “abrupt”). Our adaptations include the ability to control the direction in which the balls appear on the screen, and the addition of stimuli in a different shape (e.g., a star) as a distracter.
- **Soccer** - The user sees himself as the goalkeeper in a soccer game. Soccer balls are shot at him from different locations, and his task is to hit them with different parts of his body in order to prevent them from entering the goal area. Successfully repelled balls remain white while the ones that enter the goal change color from white to orange. Our adaptations for grading the level of difficulty include changing the number of balls that appear simultaneously as well as their direction and speed.
- **Snowboard** - The user sees a back view of himself mounted on a snowboard. As he skis downhill he needs to avoid rocks, trees and other obstacles by leaning from side to side or moving his whole body. We adapted the level of difficulty of this environment by changing the speed of skiing.

For the above three environments we added a database that records the participant’s performance.

- **Sharkbait** - The user sees himself immersed within an ocean surrounded by fish, eels and sharks. His objective is to swim within the environment and catch floating stars while avoiding the electric eels and sharks.



**Figure 2.** Screen shot of VividGroup’s birds and balls environment.

The Gesture Xtreme system appears to be suited to the rehabilitation of individuals with motor and cognitive deficits for several reasons. First, the user does not have to use a head-mounted display or other special apparatus in order to feel immersed within the virtual environment. This both reduces the likelihood of developing side effects and eliminates a source of encumbrance that would likely hinder the motor response of patients with neurological deficits. Although the newer Head Mounted Displays (HMDs) and stereoscopic glasses are considerably less cumbersome than previous models, little information is available regarding their use by individuals with cognitive deficits and brain injury.

The second feature of the Gesture Xtreme system that encourages its use for rehabilitation intervention is the fact that the user views himself actively participating within the environment rather than being represented by an avatar. The use of the user’s own image has been suggested to add to the realism of the environment and to the sense of presence (Nash et al., 2000). The third feature relates to how the user controls his movements within the virtual environments; rather than relying on a pointing device or tracker, navigation with the Gesture Xtreme environments is accomplished in a completely natural and intuitive

manner. Not only is the control of movement more natural, it also involves the use of as many body parts as are deemed to be suitable to the therapeutic goals. For example, the user may respond to the projected balls via a specific body part (e.g., the head or hand) when it is appropriate to have the intervention directed in a more precise manner, or via any part of the body when intervention is more global. Finally, the existing scenarios provide opportunities to facilitate a patient's residual cognitive, motor and sensory abilities in functionally meaningful contexts. Since the ultimate goal of rehabilitation is to maximize a patient's independence in activities related to daily performance skills, functional relevance and integration of performance components are of paramount importance.

The Gesture Xtreme system does have several limitations which should be taken into account when considering the use of this system in rehabilitation. The use of a single camera means that the environments and movement within them are essentially two dimensional. This is in contrast with HMDs in which the user is fully located within a three dimensional world. Moreover, the feedback provided is visual and auditory with no additional sensory information such as haptic. Although the haptic sense is not yet widely used in rehabilitation there is some evidence (Boian et al., 2001) that it can be an effective addition towards the accomplishment of certain treatment objectives (e.g., increasing joint range of motion and force). The various attributes of the Gesture Xtreme VR system are summarized in the table.

**Table 1.** *Attributes of the Gesture Xtreme system for intervention in rehabilitation.*

<b>Advantages</b>	<b>Disadvantages</b>
<ul style="list-style-type: none"> <li>• Use specific body part or all body parts</li> <li>• The user views himself not an avatar</li> <li>• The user controls his movements directly</li> <li>• Do not need to wear HMD, data glove or other external device</li> </ul>	<ul style="list-style-type: none"> <li>• The scenarios and interactions are two dimensional</li> <li>• Only visual and auditory feedback is given</li> </ul>

To date published reports of the use of this system have been limited to brief description of its clinical use with a small number of elderly individuals who have a high risk of falling and post stroke patients (e.g., Cunningham and Krishack, 1999). Despite the obvious methodological limitations of this study, it did demonstrate the feasibility of using the Gesture Xtreme VR system for the rehabilitation of neurological and elderly patients.

We first designed and carried out a pilot study in order to characterize the adapted virtual reality system and, specifically, to examine and describe the sense of presence it creates in comparison with a non-immersive virtual reality system, a desktop street crossing VR scenario (Naveh et al., 2000; Weiss et al., 2002). We found no significant differences in the scores of the presence questionnaire (Witmer and Singer, 1998) although there appeared to be a trend in favor of the Gesture Xtreme system (Kizony et al., 2002). When analyzing the results of a short presence questionnaire composed for the purpose of the study (based on the Witmer and Singer's (1998) presence questionnaire), which was filled by the participants after they experienced each scenario we found differences in their response to individual environments. The soccer scenario created the highest level of presence followed by snowboarding, street crossing, birds and balls and, finally, sharkbait which created the lowest sense of presence. These findings suggest that the virtual scenarios which are more functionally relevant and more similar to realistic, true to life activities such as soccer or street crossing, create higher levels of presence regardless of the type of the virtual reality system. Thus it seems that the type of the virtual scenario or environment and the extent to which it is perceived as being functional and realistic plays an important role in creating a sense of presence. Based on these results we decided to carry out our initial intervention studies with the soccer, snowboarding and birds and balls environments and not to adapt or use the sharkbait application.

The characteristics of the adapted Gesture Xtreme VR system appear to make it a potentially useful treatment tool for cognitive and especially attention deficits as well as motor impairments. For example, the adaptation will allow simultaneous movement in the environment and recognition of specific stimuli and allocation of attention to it. The ability to control the number, speed and type of stimuli enable training of specific attention components, for example, divided attention in cases where the user has to touch one

stimulus and avoid another and sustained attention when one has to sustain attention for a long period of time. This, in turn, is assumed to have a major impact on functional outcomes.

### **3. CLINICAL PILOT RESULTS**

#### *3.1 Patients with stroke (motor and cognitive deficits).*

Stroke is a major cause of disability in the adult and elderly, which can result in different motor and cognitive impairments, and functional disability (Woodson, 1995). Almost half of the patients suffering from stroke retain substantial disability (Stineman & Granger, 1991) affecting their performance of occupational activities of daily living such as bathing and dressing (Bernspong et al., 1989; Zhu et al., 1998), and sandwich and drink preparation (Katz et al., 2000). Cognitive and motor deficits have been found to be related to functional disability after stroke (Hajek et al., 1997; Katz et al., 1999). In addition attention deficits are common after brain damage (Lezak, 1995) and have severe functional consequences since the attainment of a sufficient level of attention is required for learning which is an essential process for recovery of function after brain damage (Robertson, 1999). One of the manifestations of attention deficits is unilateral neglect which is characterized by a reduced ability to respond to stimuli presented to the contralateral space (Heilman et al., 1993). Unilateral neglect was found as one of the major impairments related to decreased rehabilitation outcome after right hemisphere stroke (Kalra et al., 1997; Katz, et al, 1999; Paolucci et al., 1996).

To date we have tested three people who have had a stroke. These participants were able to use the system at different levels of task difficulty and they described the experience as enjoyable and expressed their interest in continuing to use it as part of their rehabilitation process. Their responses to the presence questionnaire indicated that they felt a marked sense of presence during their VR experiences. One of the participants suffered from unilateral neglect; analysis of his performance revealed that in the beginning of the virtual reality session he used only his right hand and did not move within the environment. As the session progressed, he began to use both sides of his body and became much more mobile. The other participant suffered mainly from motor deficits; analysis of his performance revealed an increase in his ability to raise the affected arm as well as maintain his balance. Specific performance data from these and additional participants with stroke will be presented.

#### *3.2 Patients with paraplegic (complete or incomplete) spinal cord injuries (balance training).*

Spinal cord injury can affect physical, psychological and emotional aspects of occupational performance. The impairments and disability resulting from SCI depend on the level of injury. The role of rehabilitation in these cases is to bring the patient to maximal independence in all aspects of life (Hollar, 1995). Rehabilitation after SCI encourages patients with lower, incomplete injuries to stand and ambulate with orthoses for therapeutic, psychological and functional purposes. Balance is prerequisite to functional activities in standing and depends on the integrity of the central nervous system (e.g. motor ability and postural movements and sensory information). Functional activities provide greater postural challenge; an individual's ability to engage in functional activities is often limited due to impaired balance and the need for constant upper limb support (Middleton et al., 1999). The role of the therapist is to help patients find motivating ways to maintain or improve their balance. The Gesture Xtreme VR system can provide purposeful means to improve balance in SCI patients. To date we have tested four participants with complete or incomplete low spinal cord injuries. Their responses were similar to the subjects with stroke and analysis of their performance shows that they make considerably more effort with respect to balance training and postural adjustment than during conventional training. Indeed, during the virtual reality sessions, they were able to stand while using their hands for longer periods of time. Specific performance data from these and additional participants with spinal cord injury will be presented.

#### *3.3 Young adults with cerebral palsy and moderate mental retardation (leisure, self competence, control)*

Due, in large part, to a pervasive lack of opportunity, children with cerebral palsy and mental retardation, especially those who are non-speaking, often develop dependent behavioral patterns and learned helplessness (Mirenda and Mathy-Leikko, 1989). Our major objective in using virtual environments with a group of non-speaking young adults was to improve their self-esteem and sense of self-empowerment and to give them positive experiences during physical interactions with external environments. To date we have tested 5 individuals with cerebral palsy and moderate mental retardation who are non-speaking and who are confined

to wheelchairs. These participants demonstrated an exceptional degree of enthusiasm during each VR experience, reacting to the various stimuli via appropriate and goal-oriented responses. Their responses to the presence questionnaire indicated that their level of involvement was considerable. Specific performance data from these and additional participants with cerebral palsy and mental retardation will be presented.

#### 4. FUTURE DIRECTIONS

We have begun the development of several new virtual environments, to be experienced within the Vivid platform. We contend that, to date, insufficient attention has been given towards the identification of which VR attributes are of greatest importance in achieving its effect as a rehabilitation intervention tool. These include the effect of using of two-dimensional versus three-dimensional visual presentation, representation of the patient as an avatar or as a realistic image embedded within the virtual environment, and the ability of the patient to control his location and movements via non-intuitive actions (e.g., joystick manipulation) or via natural movements. Our efforts in this direction involve the import and adaptation of Rizzo et al.'s (2000) virtual classroom and virtual office. We plan to concurrently compare subject performance (both controls and individuals with neurological disabilities) while engaged in these environments within the Vivid platform and within the customary HMD and tracker platform. Such comparisons will give us greater insight into the relative attributes of the two approaches to immersive VR and will help us to identify the ideal platform for the various therapeutic objectives in rehabilitation.

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# **Virtual reality and stroke rehabilitation: a tangible interface to an every day task**

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## **ABSTRACT**

At the University of Nottingham, UK, a project is currently in progress which is exploring the application of virtual environments for supporting stroke rehabilitation. The project has focussed on a user centred design approach and has involved consultation with stroke survivors, therapists and stroke researchers. Seminars held during the initial phase of the project offered an insight into the priorities and perspectives of these individuals, from which we identified the activity of making a hot drink as a suitable every day task to study. Although the longer term aim is to investigate a possible role of a virtual environment to support the rehabilitation of a sequential task, our immediate concern is to select a method of interacting with the virtual environment, which is both appropriate and acceptable for stroke survivors. Responding to a preference for naturalistic action and realistic scenarios, a tangible user interface to a hot drink making activity was piloted with stroke survivors resident in the community. The results of this study have improved our understanding of how stroke survivors interact with simulations and highlighted aspects in need of improvement.

## **1. INTRODUCTION**

### *1.1 Rehabilitation Of Activities Of Everyday Living Following Stroke*

Stroke is used as a broad term to describe a sudden focal neurological insult. The effect a stroke has on the person experiencing the trauma is dependent upon a number of contributing factors including severity and location within the brain. In the early stages following a stroke, perceptual deficits are a barrier to learning however as these recover, the role of the occupational therapist (O.T.) becomes increasingly important in helping the patient towards maintaining a full and independent life.

In order to achieve this goal, the stroke survivor must be capable of demonstrating an ability to perform tasks safely. In hospital or transitional rehabilitation this may involve periodic sessions during which the patient is accompanied by the O.T. and performs various activities of everyday living such as dressing, making a drink or preparing a meal.

### *1.2 Virtual Environments In Stroke Rehabilitation*

Virtual environments may offer a method of rehearsing everyday activities during which progress through the activity can be monitored objectively and physical danger is removed from the scenario. One of the compelling attributes of a VE is that the activities may be meaningful and set in the context of realism, or ecological validity. Virtual environments have been demonstrated to be reliable in the assessment and rehabilitation of cognitive functioning (Pugnetti et al, 1995; Rose et al., 1996; Rizzo and Buckwalter, 1997; Riva, 1998). VR has also been shown to be capable of improving spatial skills (Stanton et al., 1998) and learning and practice of everyday life skills (Christiansen et al., 1998; Brown et al., 1999). A hot beverage activity was the subject of a study by Davies et al (1998).

Virtual Reality is often cited as a method of replicating activities in a simulation of three-dimensional physical space. In the context of rehabilitation, controlling the time taken to complete a subtask may also be an important factor and it is has been suggested that a virtual environment may encourage the learner to complete the action by reducing the opportunity for distraction or discontinuation of the activity through what Norman (1986) calls loss of activation.

### *1.3 A User Centred Approach*

There would be little value in developing environments that are useful if they are unusable by the client group they are designed to support. The current phase of the project involves exploring suitable methods of interacting with the environments.

The initial stages of this project involved the acquisition of expert knowledge, attitudes and advice from a consortium of healthcare professionals who are involved in stroke rehabilitation and research. Seminars were held for consultants and occupational therapists, and they responded by offering advice and guidance in the choice of suitable tasks and interface requirements. The results from these seminars were presented at ICDVRAT 2000 (Hilton et al 2000). Our focus groups identified fidelity in the virtual representation of the real world environment and the control interface used as areas of particular importance.

The seminars with subject specialists were followed by seminars with stroke survivors and their carers. Two community based stroke self-help groups became involved in the project. A variety of virtual environments were demonstrated to members of these groups and these were followed up by audio taped group discussion.

### *1.4 Selecting An Every Day Task*

The user requirements of the members of these discussion groups pointed towards a desire for more access to practising everyday tasks at a phase prior to return into the community. It had already been recognised by the therapists that virtual reality might be beneficial for simulating activities which included dangerous subtasks. It was concluded that a useful every day activity that appeared to satisfy the user requirements would be that of practising how to make a hot beverage. This activity has definable boundaries with respect to sequential subtasks and has potentially dangerous consequences if performed incorrectly.

One of the concerns expressed by stroke survivors was that a VR simulation task would require additional learning in order to use the computer. This was of particular concern to some of the older clients who did not have much computing experience prior to their stroke. A potential solution was found in a project previously used with young adults with learning disability, in which a tangible interface was developed to allow manipulation of real objects to activate the sequence of subtasks, simulated within a virtual environment, for making a cup of coffee (Cobb et al., 2001).

## **2. THE TANGIBLE USER INTERFACE**

### *2.1 Consultation with Occupational Therapists*

Consultation was held with occupational therapists based in community rehabilitation to discuss a feasible approach to developing a virtual environment to the coffee-making task. Observations were made of stroke survivors being assessed carrying out a hot drink making activity in their own home environments. Members of a community nursing team accompanied these visits.

A coffee making activity had been the basis of an undergraduate project in which the apparatus required to complete the activity was simulated by toy equivalents. These were mounted ingeniously such that when an action was performed a mechanical key-press of a keyboard character was effected (Starmer 2000). Software to complement the interface had been developed using Superscape VRT which offered verbal instruction and visual feedback. The environment was a kitchen work top with the various items required to make a cup of coffee. The tangible user interface (TUI) was developed further by Tymms (2001) in an undergraduate project in which the toy objects were replaced by real world objects such as an electric kettle, jar of coffee etc., and these are shown in figure 1. The O.T.s considered that this might be a suitable starting point and confirmed that when assessing a stroke survivor they would use a kitchen scenario that was familiar to the patient prior to the stroke.



**Figure 1.** The tangible user interface to a coffee making activity.

## 2.2 Overcoming technical problems of existing devices

The existing tangible user interface required some modification before a pilot study could commence. Unfortunately it was found that some of the interactions (such as putting the kettle under the tap) resulted in a sustained string of characters rather than the single trigger that was required. Feedback sequences were continuously activated until a reset was given. Also it was found that some of the interactions were not very naturalistic. For example to spoon coffee out of a jar, required a firm push onto a fairly heavy spring loaded metal piston which was mounted inside the jar. Constructing a monostable or “one shot” multivibrator and connecting it between the TUI worktop and computer solved the problem of continuous activation of input signal. This electronic device triggers on an input signal and delivers a 500mS pulse, irrespective of the input duration.

The coffee jar lid also provided some problems as it did not operate when the lid was removed or replaced. In order to solve this, a light sensitive switch was mounted inside the coffee jar which. However it was found that when an arm stretched across the jar to pour milk, it activated the light sensor in error and the computer was given conflicting inputs, one for the milk being poured and one for the lid of the jar being removed. Finally a solution was found by simply placing a magnet on the perimeter of the jar lid and using a reed switch to make the contact.

## 3. DESCRIPTION OF THE ACTIVITY

### 3.1 Instruction, User Response And Feedback

The design for the VE coffee making activity was based on a hierarchical task analysis (HTA) conducted by Starmer (2000). This was verified against the O.T.’s activity analysis in order to confirm that this was appropriate for stroke rehabilitation (Turner 2002).

The activity is initiated by a verbal instruction delivered by the computer inviting the participant to place the kettle under the tap. The correct user response would be to pick up the kettle and place it on the worktop beneath the tap. A micro-switch is consequently triggered which signals the completion of that particular subtask. The computer responds by playing a simulation of the activity, comprising of both visual and audible analogues. For example filling the kettle will result in the sound of water and a visual demonstration showing the kettle being filled.

The simulation continues by prompting the user to proceed to the next subtask, again by verbal instruction. An incorrect or inappropriate response is countered with a verbal correction and the user may not proceed until the correct action with the correct hardware is effected.

The subtasks that the user must complete (which correspond to the instructions), and the action required to effect the subtask are presented in table 1.



**Figure 2.** An example of the screen.

**Table 1.** Subtask description and user action.

Subtask Description	User Action
Place kettle under tap	Pick up kettle Place on worktop underneath tap
Fill the kettle	Press down on the tap
Switch on the Kettle	Pick the kettle up and place on the base Press the switch on the kettle Wait for kettle to boil
Open coffee jar	Unscrew lid of jar
Spoon coffee out of the jar	Pick up the spoon Push down lightly on surface of coffee
Spoon coffee into the mug	Push the spoon gently into the mug
Replace the lid on the coffee jar	Pick up the lid and screw clockwise onto jar
Pour water into the cup	Pick up the kettle Place on the tilter Tip the kettle towards the mug
Pour milk into the cup	Pick up milk carton Tip the spout when above mug

## 4. METHOD

### 4.1 The Pilot Usability Study

Once it could be demonstrated that the TUI was technically reliable, a pilot usability study was organised. Community self-help groups were contacted and seven stroke survivors volunteered to take part in the study by self-selection. The tangible interface worktop and a Toshiba laptop computer were set up at a location which was convenient for the participants. The proceedings were videotaped using a Panasonic camcorder which was positioned to focus only on hand movements. Consent was obtained from all participants and countersigned by a carer. Two therapists were on hand in order to ensure that the instructions and activities were appropriate and to discuss the implications of results.

The procedure was demonstrated to the group and then individuals were invited to work through the activity unaided (except in circumstances where prompting was necessary). Observation notes were taken during throughout the event. A usability criteria checklist was completed, the following being of particular importance:

- Did the user respond appropriately? (correct response to the instruction)
- Errors made
- Nature of errors

## 5. RESULTS

### 5.1 The Participants

Seven stroke survivors took part in the study, of which five were male. All seven participants suffered from expressive aphasia. This is typically seen in patients with frontal lobe lesions and is often associated with errors of sequencing and attention deficits in the early stages following a stroke. All participants were living in the community where they lived independently or with support from a carer. Six participants had negligible or no use of their right arm. All participants completed the task within four minutes, with a mean time of 2min 38.46sec, however errors were frequently made and these are presented below.

### 5.2 Errors and nature of errors

The subtask description and errors made or problems encountered are presented in table 2 based upon results from all participants on first attempt following demonstration.

**Table 2.** Errors and problems encountered.

Subtask Description	Error and Problems Encountered	instances
Place kettle under tap		
Fill the kettle	Did not respond to instruction Problem with weight of kettle Problem operating switch	2 1 1
Switch on the Kettle	Placing kettle on tilter instead of base Poured water before instruction given	4 3
Open coffee jar		
Spoon coffee out of the jar	Ineffective user response Put spoon on worktop after taking coffee	4 2
Spoon coffee into the mug	Ineffective user response	1
Replace the lid on the coffee jar	Required instruction to be repeated Difficulty replacing lid	1 1
Pour water into the cup	Inappropriate action to pour water	2
Pour milk into the cup	Ineffective user response	5

## 6. DISCUSSION

### 6.1 location of objects

The TUI worktop appeared to serve as a focal point and also a physical boundary to the activity. Participants who had full or partial use of their right hand tended to use their right hand to pick up the kettle which was situated near the right boundary of the worktop. However participants with loss of movement to their right arm did not position themselves such that their left hand was aligned to the kettle. Instead they tended to reach across to the right to pick up the kettle with their left hand. Discussion of this result with O.T.s would suggest that versatility in locating items is a key factor in successful design and it is desirable to be able to relocate objects to suit the patient.

### 6.2 Instruction

All participants had expressive aphasia. They could respond to verbal instruction although it was pointed out by a speech therapist present that single mode instruction has limitations and patients with receptive aphasia would not respond to the spoken word. It was suggested that we should consider alternative modes such as textual instruction. Two O.T.s who were later consulted also suggested that a strength of the virtual environment would be in demonstrating the desired action prior to participants response.

Most participants followed the instructions that were given and did not try to anticipate future actions, however when the kettle had boiled the participants were given a verbal confirmation and three participants responded by pouring water before the instruction was given.

Another problem was that one of the instructions was directing two separate subtasks. The instruction to place the kettle on the base and switch on the kettle caused problems. One of the reasons was comprehension of terminology and in four instances the base was confused with the assistive tilting device. In one case the participant placed the kettle on the base correctly but had forgotten the second part of the instruction. This indicates that simple instructions using familiar terminology and single subtasks are important features of the instruction.

Conversely, one subtask instruction was in two parts. Putting the spoon into the jar of coffee and lifting out a spoonful was considered as one action. Pouring the coffee from the spoon into a cup was treated as another action. However two participants put the spoon down on the surface between these actions, not linking them to the same overall subtask.

### *6.3 Physical Constraints*

The kettle was too heavy for one person to lift and this causes somewhat of a paradoxical situation. Therapists have told us that the environment should represent a scenario familiar to the patient prior to their stroke, however the stroke itself may have caused a physical impairment which prevents them from carrying out the activity as they did previously. The physical constraints of the TUI are important factors to successful design and the capabilities of the user must be taken into account. A solution may be to develop a TUI in which objects are representative of real world objects but easier to manipulate. This would not conflict with the purpose of the TUI for practising sequential tasks providing the actions were similar to the real world task.

### *6.4 Ineffective user response*

For certain interactions participants experienced some difficulty effecting a subtask completion trigger. Spooning coffee out of the jar and into the cup relied upon the user pressing down into the vessels in order to operate a micro-switch. Pouring milk required the user to use a pouring action with the carton. It is apparent from video analysis that object recognition is not an issue in these circumstances. The appropriate apparatus is employed however it appears that participants may be cautious about pressing too hard and are not activating the switches effectively. A more sensitive yet robust and discriminating method of actuation is possibly required.

### *6.5 The Virtual Environment*

Participants appreciated the visual and auditory feedback but they felt that the layout could be improved. From certain angles objects were partially obscured. For example in one scene the coffee cup obscured the coffee jar label. They suggested that an improvement would be to show the liquid levels corresponding to user input. Both the therapists present and the therapists consulted later suggested that they felt that there was little point in playing back a prepared sequence, but that the virtual reality aspect would be useful if the feedback was more representative of the consequence of the action. However they added that value would probably be added to the system if tracking of the actual hand movements throughout could be played back to the patient upon completion of the activity.

## **7. CONCLUSION**

Following a cycle of consultation involving OTs, stroke researchers and stroke survivors we have acquired perspectives and criteria which are considered of importance in the design and development of virtual environments for the rehabilitation of the stroke survivor. As a result we have identified making a hot drink as an everyday task to study and proceeded by exploring the interaction between the patient and the virtual environment.

In order to reduce the need to learn a new skill we have pursued the development of a tangible user interface to the environment and studied user acceptance and usability. The initial study has provided us with an insight into the important aspects of designing V.E.s when the primary user has experienced the trauma of a stroke. The objective of the exercise was to identify criteria for a future design and therefore we are not intending to demonstrate any improvement or deterioration in performance at this stage.

The immediate plan for this project is to redesign the tangible interface and the environment taking into account the improvements suggested by our consultation groups. The hardware performance will be reviewed and improved. The environment will endeavour to offer suitable and adequate feedback for each subtask, corresponding to the result of the action performed, rather than imitating the action. A further development that is under investigation is that of hand tracking and therapists confirmed that they would consider the ability to record and play back the patient's hand movements as having substantial value.

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# **Virtual reality in stroke rehabilitation with the assistance of haptics and telemedicine**

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## **ABSTRACT**

A 3D-computer game was used as a training utility to promote motor relearning on a telemedicine platform in a laboratory setting. The subject suffered from a left arm paresis. He was evaluated before and after treatment with a specific hand function task, a standardized grip force measure test and an upper extremity task. Grip force, endurance and the movement pattern of the upper extremity improved after the treatment. The telemedicine platform allows the professional to record and evaluate progress. The findings implicate that training with Virtual Reality and Haptics can promote motor rehabilitation.

## **1. INTRODUCTION**

The impairment of the upper extremity is a prime obstacle in re-acquiring competence in managing every day activities. Stroke survivors (Feys et al, 1998) perceive the loss of upper extremity function as a major problem. Broeks et al (1999) assessed the long-term motor and functional recovery of arm function after strokes and concluded, as many before, that there is a need to develop active treatment methods for upper extremity function. After discharge from hospital units many patients with prior stroke are still in need of qualified rehabilitation. Yet, the alternatives given to patients after discharge from hospital units are limited in availability and vary locally/regionally (National Board of Health and Welfare, SWEDEN, 2001). Target oriented rehabilitation approaches and individually adapted training programs are essential in order to gain recovery. The recovery of the affected upper extremity is as in every other training situation dependent on regularity and intensity in training (Kwakkel et al, 1999), as well as on specificity. In order to stimulate the recovery, the training program must allow the individual to development and re-establish their motor system. Training programs should be made engaging in order to motivate the patient. Home rehabilitation might be an important complement that can produce results comparable to institutional rehabilitation (Duncan et al, 2001). In relation to the traditional approaches, new models must be developed for patients and health professionals. Providing rehabilitation in the home makes the role of telemedicine evident.

Virtual Reality (VR) technology is presently being explored as an assessment and training device for improving motor recovery after stroke (Holden et al, 1999, Burdea et al, 2001, Piron et al, 2001, Broeren et al, 2002). However, when performing tasks with the effected upper extremity in VR environments, which often means manipulating objects, the need for haptic force feedback becomes evident. In order for VR to better approximate reality for tasks, the senses of touch and kinaesthesia must be addressed.

The aim of this study is to make VR applications of existing occupational treatment methods and to develop a platform for home rehabilitation controlled telemedically where we emphasize on building a low-cost web-based video/audio telemedicine system.

## 2. MATERIAL AND METHODS

### 2.1 Design

A single-subject ABA research design was used (Zahn S, Ottenbacher KJ, 2001). Before the training, the subject was evaluated with a test battery (see below) followed by a 4-week training period (frequency: 3 times a week for 90 minutes each time). After the training period the subject was tested with the same test battery.

### 2.2 Subject

One male subject was included in this study, age 59 years. The time since stroke was 3 months. He had a first occurrence of a stroke, i.e. sudden occurrence of neurological deficits due to impaired blood flow in the brain due to either infarction or haemorrhage. In this case, the cause was an infarction, and the diagnosis was set by a clinical neurologist after examination and confirmed by CT-scan. He had a paresis in the upper left extremity (right hemisphere lesion) and normal spatial competence and body awareness. There were no limitations in understanding the information given

### 2.3 Haptic system and Telemedicine Platform

The computer hardware consists of an Intergraph Zx10 ViZual Workstation (2 x 750 MHz Pentium III with 512 Mb RAM and a WildCat 4110 graphic card, Windows 2000). Haptics are added using Reachin 3.0 from Reachin Technologies AB (Stockholm, Sweden). Reachin API is a programming environment allowing interactive manipulation of a 3D model using a haptic interface. Haptic force feedback is provided using the PHANTOM™ haptic device (SensAble Technologies Inc., Woburn, MA, US). Stereoscopic visualization is accomplished using a standard CrystalEyes CE-2 setup (San Rafael, CA, US).

The Telemedicine platform is based on two standard computers, high performance web cameras (Philips Electronics N.V., Eindhoven, the Netherlands), the World Wide Web and low-cost Teleconference Application. The application uses protocols within the TCP/IP suite and enables the transfer of log files that show the patients results, and data concerning video/audio teleconference between the patient and the clinical personnel.

### 2.4 Training procedure

The subject was trained with a computer game (3D-bricks), which was originally developed by Reachin Technologies AB. At the start of the game, the subject grasps the PHANTOM™ haptic device with his left hand. He obtains a view of a ball in a court filled with bricks. The game starts when the subject strikes the ball. The subject receives credit for the bricks knocked down. On the return, when the player missed the ball, the player collected minus points. The game was customized to operate at four levels of different speed. The effect of modifying the speed from 4-3-2-1 caused the program to speed up the velocity of the ball. The level of difficulty was changed after the subject had reached a given score of three consecutive games

### 2.5 Test procedures

Three tests were used to evaluate motor performance of the left upper extremity. It was evaluated in the following order: 1) Fine manual dexterity was measured by using the tasks of the Purdue pegboard. This test consists of manipulating small pins on a board as quickly as possible in a 30-second period. The score is the number of pins handled. 2) The dynamometer hand grip strength by Grippit™ (AB Detector, Gothenburg, Sweden) was recorded. Peak maximum grip force and the mean value of the 10-second sustained grip were measured. 3) A upper extremity test was developed. The subject had to move the PHANTOM™ haptic device to different targets (generated positions) on the screen. The target placements (32) were apparently random to the patients, but actually set according to a pre-set kinematic scheme. The targets were numbered from 1-9, by starting with no 1 at the lower part of the right hand side of the computer screen, continuing with no. 2 and 3 to the left. The fourth target is placed above target no 1, no. 5 over no. 2, and so on. The motions of the left upper extremity were divided in different directions, i.e. sideways (left – right and right – left), up and down, diagonal (left – right) up and down. The x-, y- and z-coordinates for the haptic device and the targets were continuously sampled. Thereby, the kinematical pattern, time, speed, trajectory distance (actual passway of the upper extremity) and intertarget distance (geometric shortest distance between the targets) to complete the exercise were computed, constituting a measure by which the performance was evaluated.

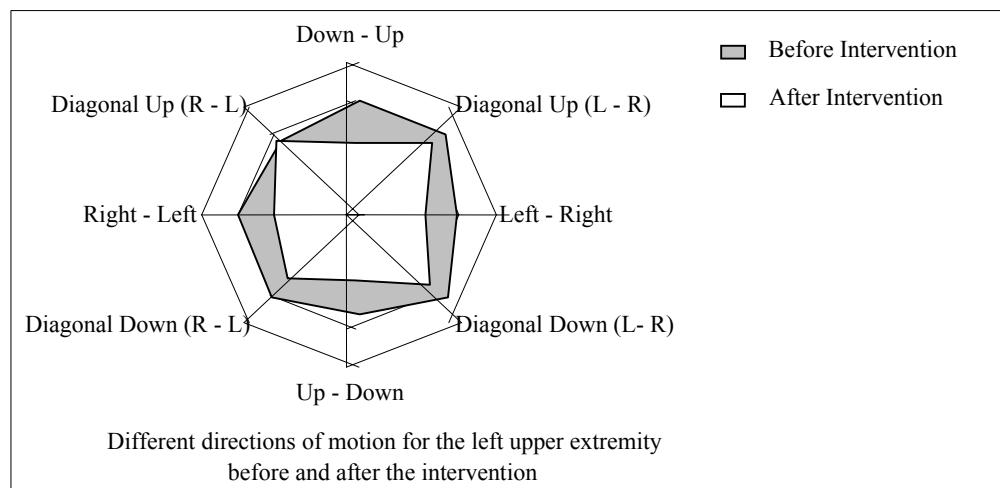
### 3. RESULTS

Comparisons of pretreatment and post-treatment measures were used to indicate changes. Both the fine manual dexterity scores and the grip force changed for the subject after the intervention period (Table 1). The grip force improvement increased considerably, this change could elucidate the improvement in endurance while playing the virtual game. By the end of the intervention period, the subject progressed to game level 1 (most difficult).

**Table 1.** Results of the Purdue pegboard and grip force.

		Pre-treatment		Post-treatment
Time after stroke		1½ weeks	2½ weeks	11 weeks
Fine manual dexterity, No. of pins	left hand	impossible	impossible	6
	both hands	impossible	impossible	3
Grip force, N	mean	46	20	52
	peak	172	120	68
1 N = Newton				

Figure 1 shows the kinematic pattern before and after the intervention. The subject shows an altered movement pattern after the intervention period. As seen in fig. 1 the subject improved in almost all direction, except for the Diagonal Up (R – L) direction. The enhanced motor pattern i.e. the shorter trajectory distance is due to the better precision to strike the targets. This is also verified by the improvement of the fine manual dexterity task. For exact measures see table 2. Morphologic changes of the movement pattern correspond to the improvement in (fig 2 and fig 3).

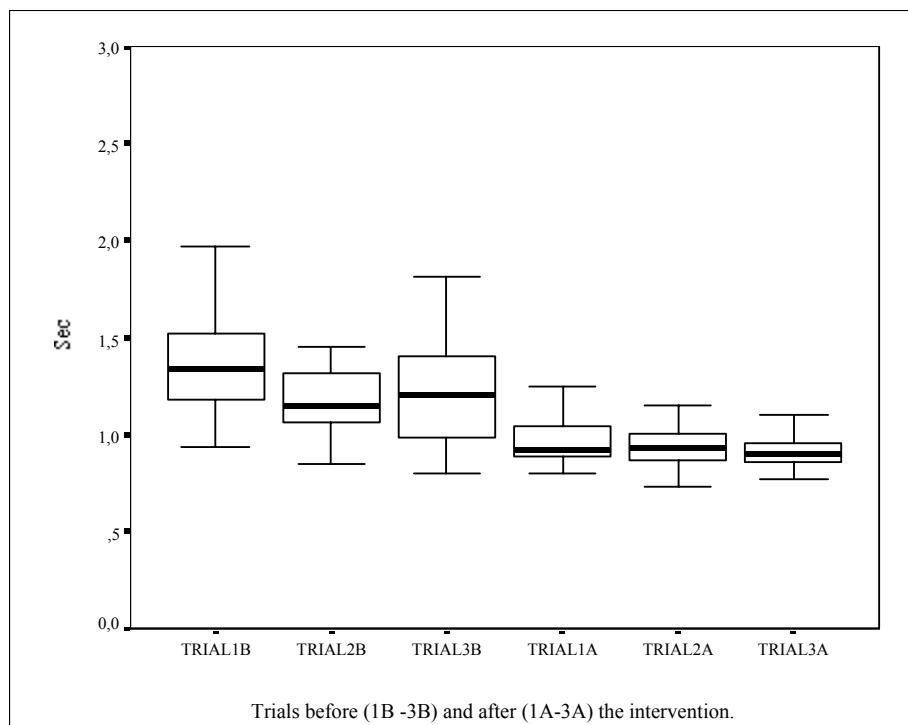


**Figure 1.** Kinematic pattern (mean trajectory distance) before and after the intervention.

**Table 2.** Mean trajectory distance (m) for the directions of motion.

	Before Intervention	After Intervention
Down – Up	0,3006	0,1869
Diagonal Up (L - R)	0,3004	0,2685
Left – Right	0,2369	0,1723
Diagonal Down (L- R)	0,3057	0,2611
Up – Down	0,2638	0,1732
Diagonal Down (R - L)	0,3043	0,2319
Right – Left	0,2993	0,2021
Diagonal Up (R - L)	0,2696	0,2702

The median inter-target time for the subject time to complete the tests improved (fig 2). The median times for trials 1B - 3B were 1.3, 1.1 and 1.2 sec before the intervention. After the intervention the time increased considerable into 0.92, 0.93 and 0.90 sec for the three trials (trial 1A -3A).



**Figure 2.** Time (sec) to complete the exercise. Median values 10<sup>th</sup>, 25<sup>th</sup>, 75<sup>th</sup> and 90<sup>th</sup> percentiles.

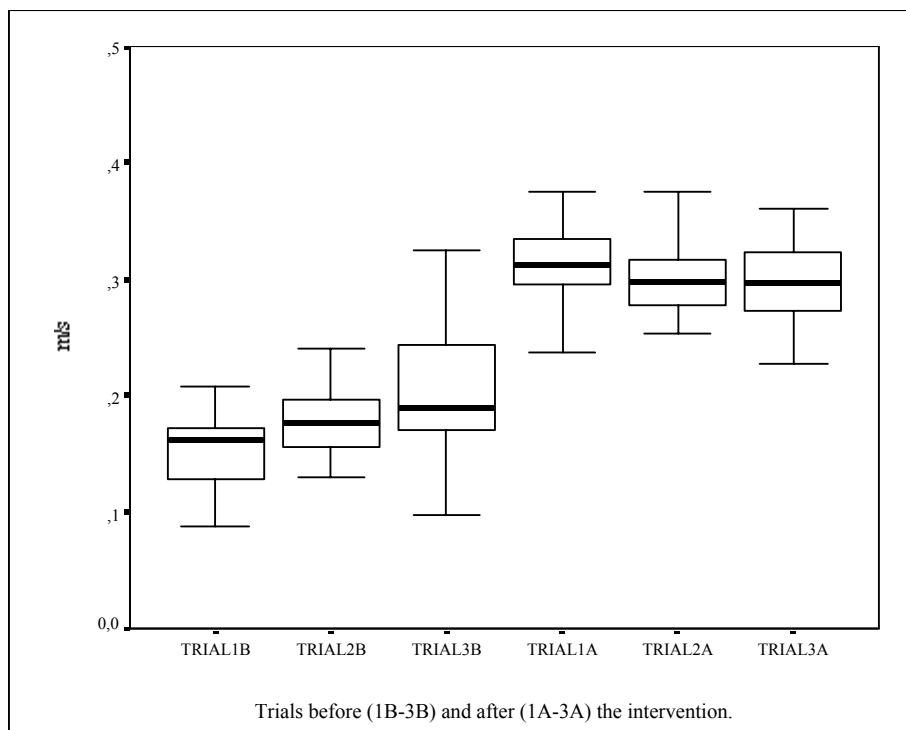
The velocity is the speed (m/s) along the trajectory of the haptic device and is not calculated from the intertarget distance (fig 3). Even in speed there was an improvement. The median velocity before the intervention were for trials 1B – 3B; 0.16, 0.18 and 0.19 m/s. After the intervention the velocity was more or less equal, 0.31 m/s for trial 1A and 0.30 for trials 2A and 3A.

The subject had previous experience of communicating with computers and used it as a telephone for his long distance calls. The subjects spontaneous reaction about the telemedical communication were that the picture and the sound were well synchronized, the communication felt “close”, quick and of a good quality. He also stated that it’s more convenient; “you don’t have to travel into town, wait a couple of hours, make a quick exercise and then call the transportation service for older persons again and finally travel home again”.

#### 4. DISCUSSION

The findings in this study implicate that virtual training of the effected upper extremity can promote motor rehabilitation. We investigated fine manual dexterity, grip force, motor patterns and velocity performed with affected upper extremity. A single subject research design was used. With a single subject design conclusions can be drawn of treatment effectiveness (Zahn S, Ottenbacher KJ, 2001). We observed that grip force, endurance and the motor pattern of the upper extremity increased after the treatment, which started 11 weeks after the stroke. The results imply that intensive training can reduce motor impairment and that it could optimize the stroke survivor’s motor skills. This is in line with the results of Copenhagen Stroke study (Nakayama H, Jørgensen HS, Raaschou HO, Olsen TS, 1994) where they show that the time course and degree of upper extremity function after a stroke with initial paresis basically occurred within the first 3 weeks and no further recovery of upper extremity function should not be expected after 11 weeks. For example, the subject’s velocity and time to complete the trials improved to a large extent, indicates that this might be an effective method to improve motor recovery. The kinematic motion pattern changed to some extent, with still difficulties in some direction, above all in the diagonal directions. The superfluous upper extremity movements along the trajectory to the target can be calculated. The quotation of the actual

trajectory distance and the intertarget distance reflects the uncertainty of the upper extremity along the trajectory. This information can be the base for developing rehabilitation programs for upper extremity training.



**Figure 3.** Velocity (m/s) to complete the exercise. Median values 10<sup>th</sup>, 25<sup>th</sup>, 75<sup>th</sup> and 90<sup>th</sup> percentiles.

The telemedicine application used was Microsoft NetMeeting 3.01. The main reasons why Microsoft NetMeeting were chosen was that it is a solid and fully tested software suite that provides an industry standard, good operating system residency, high performance and a smooth integration with other programmes at a low cost. The system was used as a personnel-patient communication tool before, after and even during the rehabilitation exercises, giving the patient the opportunity to e.g. show a hurting muscle group, his motor status and ask questions. In addition, the health professionals could for example instruct the patient, make a visual examination/status of the patient's motor capacity. The clinical advantage of using such a system is considerable. The trend is toward shorter hospital stays and fewer outpatients' visits. Today it is difficult to check a patient's progress once discharged from hospital. In order to reassure the patient's progress with their training programs new approaches must be adapted. The system probably demands, as today, good computer knowledge.

For an application like home care telemedicine, for people with neurological disorders, more development have to be done before this will be broadly accepted by patients and health care providers. Work need to be done in the following fields:

- Integration, interconnectivity (e.g. integration with electronic health record systems)
- Safety/privacy (e.g. on Internet)
- Standardization (e.g. in the field of home care telemedicine)

In conclusion: One subject with left hemiparesis improved his motor pattern, grip strength and manual dexterity. The results verify the efficacy of the treatment and justify further clinical trials. A larger trial is required to determine difference in improvement in motor abilities of the upper extremities in stroke survivors.

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# Errorless learning using haptic guidance: research in cognitive rehabilitation following stroke

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## ABSTRACT

This paper presents an approach to rehabilitation of cognitive deficits following stroke using haptic guided errorless learning with an active force feedback (AFF) joystick and computer. While errorless learning (EL) is a proven method of teaching new information to individuals with memory problems, its effectiveness with other types of cognitive and perceptual motor deficits has not been explored. We investigated the effectiveness of haptic guided EL compared to trial and error (errorful: EF) learning on a perceptual motor task with twelve patients who had visuoperceptual deficits following stroke. Individual and group results are discussed.

## 1. INTRODUCTION

### 1.1 Cognitive Deficits Following Stroke

Cognitive deficits are a well known problem associated with many disabling conditions, such as traumatic brain injury, stroke, and other neurological disorders. The incidence of cognitive deficits following stroke has been estimated to be greater than 35% (Tatemichi et al, 1994). Impairment in global cognitive functions, attention, and psychomotor performance are significantly impaired in ischemic stroke patients regardless of the normal effects of aging (Elwan et al, 1994). Cognitive impairments following stroke result in poorer rehabilitation outcomes (Jeffrey & Good, 1995; Kwa et al, 1996), decreased quality of life (Riddoch et al, 1995), and increased incidence of depression (Lacritz & Cullum, 1998; Starkenstein and Robinson, 1989, 1990), with post stroke depression having been found to impair cognitive functioning (Lacritz & Cullum, 1998) and to be associated with poorer social functioning (Clark & Smith, 1998).

Their presence may be less obvious, but potentially as disabling, in conditions such as multiple sclerosis, drug and alcohol related disorders, and psychotic disorders such as schizophrenia. Regardless of the cause, cognitive deficits pose problems to the rehabilitation process. Examining some of the potential cognitive problems resulting from stroke is illustrative. Stroke can cause impairments of comprehension, memory, visual recognition, attention, and sequencing of actions that can have profound effects on physical functioning. To benefit from physical rehabilitation patients must be able to understand the therapist's commands, remember instructions, recognize physical objects in the environment, attend equally to both sides of space, maintain arousal levels sufficiently to co-operate throughout a treatment session and continue to utilize what the therapist has taught in their everyday lives (Riddoch et al, 1995). If the aim of rehabilitation is to optimize treatment outcomes then all factors influencing these outcomes need to be addressed, including cognitive impairments, in designing effective systems for intervention.

### 1.2 Haptic Guidance in Rehabilitation Robotics

Traditionally, the use of haptic guidance in the field of rehabilitation robotics has focused on physical disabilities where robotic guidance is used as a substitute for absent or diminished motor function. More recently there has been increased interest in robotic aides for motor rehabilitation (van Vliet & Wing, 1991).

For example, Krebs et al (1998), using robot-guided rehabilitation (a robotic arm) with stroke patients, demonstrated that robot-guided therapy does not have adverse effects, patients do tolerate the procedure, and brain recovery may be aided in the process. In their experimental paradigm, power assistance was used to enhance movements being made by the patient.

The broad aim of our work is the development of clinical applications of haptic guided errorless learning and evaluation of its effectiveness with cognitive problems in addition to memory. In the paradigm we describe, haptic guidance provided by a 'robot' was used for cognitive rehabilitation to retrain diminished function following non-progressive brain injury. We combined EL, a proven method of teaching new information to individuals with memory problems, and an AFF joystick capable of preventing errors from being made during learning. Haptic guidance used for cognitive retraining offers potentially a new area for rehabilitation robotics, relevant to perceptual motor skills, assisted by EL.

### *1.3 Errorless Learning*

Errorless learning involves preventing or minimizing errors from being made during early learning trials, especially the initial trials. The foundations of EL were established in studies by Terrace (1963) who disputed the general acceptance of responding to non-reinforcing stimuli (errors) as a necessary condition for discrimination learning to occur. In his experiments pigeons were trained to respond to a stimulus correlated with reinforcement (correct or error free choice), a red typewriter key, and not respond to a stimulus correlated with non-reinforcement (incorrect or errorful choice), a green typewriter key—a discrimination pigeons would find difficult to make. One group of birds was trained under errorless conditions in which fading in of the "error" key color was done early in training and while the pigeon's head was turned away, making it difficult to respond. The other groups were trained in more traditional methods including no progressive key color changes and late introduction of the "error" key color. One interesting observation during these experiments was that pigeons in the errorless group showed behavior that was less agitated during the test phase than the other training groups.

Memory for material learned errorlessly has most often been attributed to implicit memory processes. Baddeley and Wilson (1994) proposed that one of the major functions of explicit memory is the elimination of learning errors. Explicit memory is facilitated by devoting full attention to the material to be remembered. In contrast, responses based on implicit memory are dependent upon emitting the strongest response. If erroneous responses are allowed to occur they are then strengthened across repeated learning trials. For EL to be successful the procedures need to be "foolproof," with learning tasks kept simple, guessing discouraged, and correct responses provided before the individual has a chance to make an error. A variety of techniques have been employed to prevent errors from being made during the learning process. For example, "forward chaining" involves learning the first step of the task correctly before the second and subsequent steps are taught. "Backward chaining" takes a reverse approach in which all steps of the task are completed with prompts followed by gradually withdrawing prompts from the last step then subsequent steps in reverse order of their occurrence in the task. "Vanishing cues" is similar to backward chaining in that cues or prompts are progressively removed.

Beginning in the early 1990's these EL techniques were successfully applied to the memory rehabilitation of individuals with brain injury and were found to be superior to EF learning (Baddeley & Wilson, 1994; Wilson et al, 1994; Wilson & Evans, 1996). While individuals with intact cognitive abilities are able to learn from their mistakes, research in the field of cognitive rehabilitation with memory impairments has demonstrated that conscious awareness during learning is important for error correction to occur. For many individuals with brain injury this conscious awareness, or explicit memory of the event, is diminished or unavailable. The initial response is typically unconsciously remembered and repeated, regardless of whether it is a correct response.

In a series of single case studies comparing EF and EL with amnesic participants, EL consistently resulted in superior performance, including assisting a stroke patient to learn the names of people (Wilson et al, 1994). In a subsequent study (Evans et al, 2000) in which nine different experiments were completed with amnesics, EL was found to be the superior method for tasks and situations dependent upon retrieval of implicit memory, however, tasks requiring the explicit recall of novel associations were remembered more successfully with the EF technique. We hypothesized that perceptual motor deficits following stroke would be more responsive to rehabilitation approaches relying on implicit memory.

Errorless learning has also been used in physical rehabilitation. Biomechanical control of the environment has been shown to prevent learning incorrect movements (Butler & Major, 1992). For example, only one

segmental joint may be targeted for training while the remaining involved joints are kept immobilized. This type of targeted learning of motor control is analogous to the ‘chaining’ procedures previously described. An added benefit of EL is the resilience to increased cognitive demands. Masters, MacMahon, and Pall (in press) found, when Parkinson’s patients were trained errorlessly using physical guidance in a simple motor task, hammering, there was no difference between the EL and EF groups once the guidance was removed. This result was expected as the training did not influence the neurotransmitter disturbances in the basal ganglia that characterize Parkinson’s Disease. However, under dual task conditions carried out post-training, the EF group’s performance became significantly worse, while the EL group’s performance was unchanged. The implication from this study of the effect of EL motor learning for stroke patients is the added benefit of being able to simultaneously engage physically and cognitively demanding tasks such as walking using a hemiparetic limb while carrying on normal conversation.

## 2. METHOD

*Hypothesis: EL training, using a haptic feedback joystick, will result in faster and more direct movements to targets in a visuospatial training task for stroke patients with visual perceptual deficits.*

### 2.1 Participants

In this 18 month project, funded by the British Stroke Association, 12 independently living, community based male and female participants, 12 months or more post-cerebrovascular accident, ranging in age from 38 to 83, from the United Kingdom were recruited. Recruitment took place through a variety of sources including geriatricians in local health authorities, Stroke Clubs (community based support groups), and the University of Birmingham, School of Psychology patient panel volunteers. No patient was refused entry into the study on the basis of nature or severity of deficits, and severity of deficits was not stratified across groups.

### 2.2 Sample

All individuals in the study had evidence of some form of visuospatial processing difficulties, however, the number and severity of deficits ranged from minor visual memory problems to profound impairments across all neuropsychological measures of interest.

### 2.3 Assignment

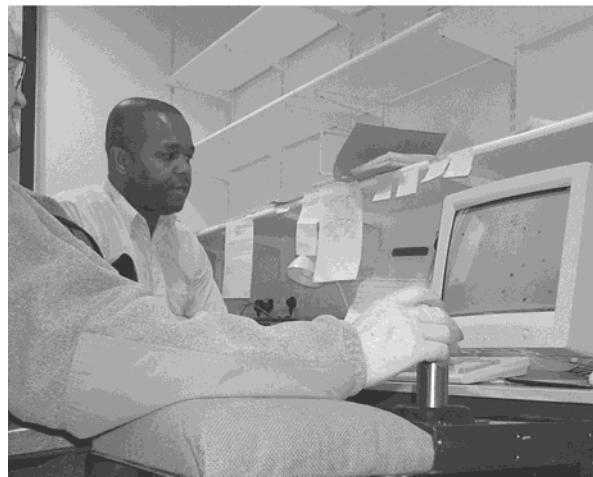
Participants were pseudo-randomly assigned to either the EF training first group (group 1) or EL training first group (group 2) based on alternating the training type as each individual completed the pre-test phase. In the original assignment, six patients were allocated to each group, however two patients in group 2 did not complete the experimental paradigm and two patients in group 1 showed only minor visual memory problems, with no other visuospatial deficits.

### 2.4 Apparatus

**2.4.1 Equipment description & operation.** The equipment used in this study, a joystick and electronic gearbox unit, act as an input device to a standard desktop computer via an interface device. Users are able to interact with the computer by moving the joystick which controls an onscreen cross cursor, ‘+’, capable of being moved around the entire screen domain. Users are able to move between stimuli displayed on screen and make selections by pressing a button on the top of the joystick. The joystick moves in a pitch and roll two dimensional plane. Any movement of the joystick generates a corresponding cursor movement on screen. Moving the joystick forward moves the cursor up, moving backward moves the cursor down, and side-to-side movements produce corresponding left or right cursor movements on screen. Operation of the joystick makes it possible to intercept targets appearing at any x/y coordinate on the computer screen. The interface programming allows for two modes of joystick operational control, EL and EF, which are set by the experimenter. Additionally, other parameter settings are available that allow for visual and auditory knowledge of results (KR), setting error margins, and selecting stimulus materials. The user moves the joystick to find a particular target on screen and makes a selection by pressing the button on the joystick. See Fig. 1.

**2.5.2 Errorless or guided mode.** In the guided or EL mode the system defines a ‘force field valley’ within which the joystick may be moved, which prevents movement to incorrect targets on the screen. The joystick does not move the user to the correct target but facilitates target acquisition by generating force field

resistance against movements in any trajectory other than a straight-line path to the correct target. This sensory information comes in the form of haptic sensation (touch) via force resistance from the joystick whenever the user attempts to move it in an incorrect direction, thus allowing the user to sense the joystick's path of least resistance. By preventing movement to incorrect targets the joystick facilitates EL.



**Figure 1.** *AFF Joystick and computer display.*

**2.5.3 Errorful or non-guided mode.** In the non-guided or EF mode the joystick's force feedback parameters are switched off allowing for unrestricted movement. In this mode of operation, target acquisition is dependent upon the user's ability to manipulate the joystick thus allowing for trial-and-error, EF, learning.

## 2.6 Procedure

**2.6.1 Neuropsychological Testing.** Prior to beginning the experimental training, a comprehensive neuropsychological battery was administered to each patient. Measures relevant to visuospatial abilities were examined to determine appropriateness for the experimental task. These measures included: two subtests from the WAIS-R (Wechsler, 1981), Block Design (BD) and Digit Symbol (DSy); two from the WMS-R (Wechsler, 1987), Visual Reproduction Immediate (VR-I) and Delayed (VR-II); the six conventional subtests of the Behavioural Inattention Test (BIT) (Robertson et al, 1994); Map Search subtest (MS) from the Test of Everyday Attention (TEA) (Wilson et al, 1987) ; and Trail Making Test A and B (TMT-A & B) (Army Individual Test Battery, 1944).

**2.6.2 Training.** Each individual received both EF and EL training in order of presentation according to group assignment, which included similar but different visuospatial processing content in the two training conditions. Training occurred for one hour per day, one day per week, for four weeks in each training condition. Between the two types of training were three weeks in which the patient came in one day per week for repeat administration of the initial baseline tasks.

Training to improve visuospatial skills employed letter/number trail-making in which the patient was presented with an array of characters, either letters of the alphabet or numbers, which appeared among star-shaped distractors on the computer screen. These letters or numbers were to be marked in sequential order. There were gaps in the target strings (e.g. A,B,D,F,H,I,M) such that the individual needed to maintain in working memory the previously marked target while locating the next in order. Graphical displays for the tasks were created using bit maps developed within MS Paint. During each block of stimulus presentations patients moved the on-screen cursor between stimuli displayed on the computer screen making their target selections by depressing the button on top of the joystick. Visual and auditory KR was provided on each stimulus item. All participants used their unimpaired ipsilesional upper extremity to move the joystick.

## 3. RESULTS

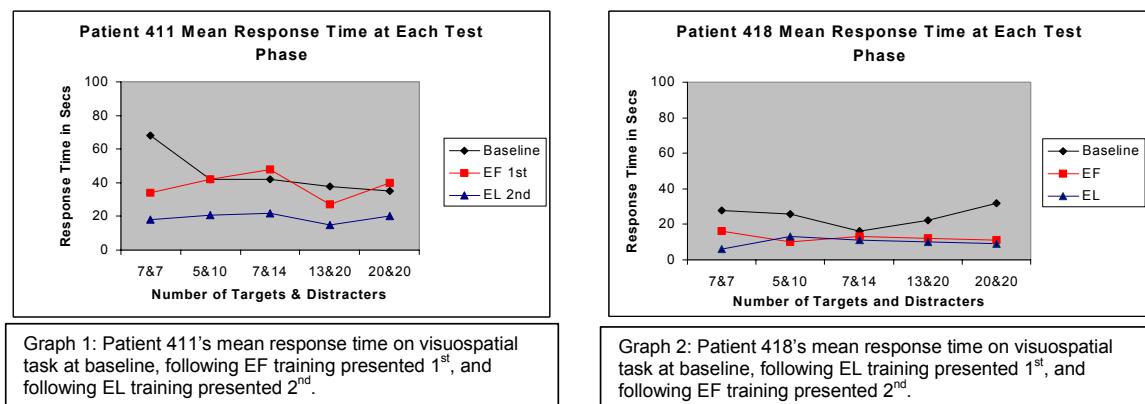
### 3.1 Data Analysis

In the data analysis, each patient's results were treated as a separate experiment in a single case series. Results were analyzed for two aspects of data collection: 1) response speed—the time from first button press at the beginning of each trial to final button press on last target of that trial, and 2) perpendicular distance—

the maximum deviation from the straight line path in the trajectory from start location to target for each target in a trial. While accuracy data were collected this information proved to be uninformative for either omitted targets or target acquisition. Both time and perpendicular distance from the straight line trajectory offered more useful information about improvements in visual scanning. Data were collected at three test phases: 1) pre-training, 2) at the end of training period one, which was also prior to beginning training period two, and 3) following training period two. At each test phase task parameters progressed across five combinations of targets (T) and distractors (D): 7 T—7 D, 5 T—10 D, 7 T—14 D, 13 T—20 D, and 20 T—20 D.

### 3.2 Individual Analyses

Graphs 1 and 2 below show the response time performance of two patients who, on entry into the project, showed significant deficits in performance on all visuospatial neuropsychological measures. Both showed evidence of profound impairment on visual memory and processing speed measures. On paper and pencil letter-trailmaking both were unable to maintain the set-shifting involved in Trails B, showing obvious sequencing confusion. Patient 411 received EF training first and patient 418 received EL training first in order. For both, phase of training showed a significant main effect on response speed in favor of the EL training, and approached significance on trajectory for patient 418. EL training resulted in a significant improvement in response speed that was maintained across all levels of difficulty, compared to pre-training performance. Training also produced more consistent trajectories across all levels for patient 418 but had no effect on the variability of the trajectories for patient 411.



### 3.3 Group Analysis

A group analysis was carried out comparing group 1 with group 2. The informative value of this analysis was limited by small sample size, unequal group sizes at completion, and heterogeneity of groups. Left versus right visual field presentation of targets and line bisection analyses for the visual scanning study did not reveal differences between the two groups.

Taking a frequency count approach, four of the participants in group 1 and one in group 2 showed significant improvement in response speed as a result of training, with only one showing a definite advantage following the EL method. The others who benefited from training showed no advantage for either method. There was very little gain in straightness of trajectories following either type of training, and for one individual (411) performance was worse following both training types, despite his gains on overall response speed as a result of training. Only one individual's variability of trajectories benefited from training, which became more consistent at all levels of difficulty following both training modes.

From a clinical standpoint, since participating in training, one individual resumed painting as a hobby which she had been unable to do post-stroke. Another participant, a retired engineering technician with unilateral spatial neglect, was able to reduce his response speed to targets, regardless of visual field presentation, by half. The patient with the most profound visuospatial deficits, who during EF training evidenced difficulty maintaining attention and was observed to go to sleep on occasion when unable to find the target, showed immediate improvement in response speed at the more complex distracter levels as a result of training. The change in clinical picture for some participants suggests there are as yet unmeasured gains from participation in this training paradigm.

## 4. CONCLUSIONS

In conclusion, in our group analysis we failed to support the hypothesis that EL training, using a haptic guidance joystick, would result in faster and more direct movements to targets in a visuospatial training task for stroke patients with visual perceptual deficits. There were individual gains from this approach, as noted above, suggesting that the concept of using EL integrated with haptic guidance can benefit some patients, but not all. This result may be a function of the task design in which the gaps in the number or letter sequence required maintaining the last character before the gap in working memory until the next character is located. Working memory, as a component of the explicit memory system, would not be influenced by a training task based upon implicit memory approaches. The training task may have required recall of novel associations which has been shown to be remembered more successfully with the EF technique (Evans et al, 2000). Another factor which may have influenced the outcome is the frequency and duration of training. A once per week training schedule may not have been frequent enough for the participants to maintain gains achieved during individual training sessions across the span between training sessions.

Completion of this initial experiment in the use of haptic guidance for EL in cognitive rehabilitation has provided a wealth of information for designing subsequent rehabilitation training experiments using robotic guidance. Based on this initial study, we conclude that patients need to be carefully stratified among experimental and control groups for age, severity of stroke, and severity of neuropsychological deficits. Additionally, the training tasks need to be carefully matched to the deficits of each patient. Finally, the schedule for duration and intensity of training needs to be examined to ensure that enough training, appropriate to individual needs, is delivered.

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# ICDVRAT 2002

## Session IV. Brain Injury and Rehabilitation

Chair: Helen Neale



# Functional magnetic resonance imaging investigation of allocentric spatial memory using virtual reality in patients with anoxic hippocampal damage

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## ABSTRACT

The involvement of the hippocampal formation in spatial memory was explored in two single case studies in which anoxic brain damage had produced selective bilateral damage to this structure. To test spatial memory a virtual reality Arena task was designed, consisting of a circular space surrounded by pattern rendered walls. The participants had to navigate within the arena using a joystick to signal motion. In an encoding phase they had to move towards a pole, situated within the arena. The pole was then removed and they had to move towards where it had been either (allocentric) from a different direction, or (egocentric) from the same direction. Brain activity was recorded during the different phases of the task in control participants and then in hippocampally damaged patients. In the controls, bilateral hippocampal activity was found in the allocentric condition only, with a network of activation in other brain regions, associated with spatial processing in both the allocentric and egocentric conditions. Hippocampal activation was not seen in either of the patients, but the remainder of the network showed normal activation.

## 1. INTRODUCTION

Virtual reality (VR) is a convenient and effective methodology for investigating spatial memory, in which a large variety of spatial domains can be created in a manner that affords experimental control and enables interactive spatial exploration. Indeed, the neural basis of spatial memory has already been studied using VR, either with functional neuroimaging or by investigating patients with focal brain lesions (e.g. Burgess et al., 2001; Morris, Parslow and Recce, 2000).

The precise neural mechanisms supporting spatial memory are currently under investigation, but a main theory is that spatial information is coded in the hippocampus in the form of *Cognitive Maps*, which specify the directions and distances between objects within the environment (O'Keefe & Burgess, 1996). This representation is essentially allocentric, in that it is independent of bodily orientation and can be contrasted with egocentric spatial memory, in which distances and directions are specifically coded in relation to the bodily axis.

In humans, spatial memory impairment has been found following temporal lobe particularly if this is in the right hemisphere. This includes impairment in memory for location, demonstrated in a landmark series of experiments by Smith and Milner (see Smith, 1989). Here participants are typically shown an array of objects and subsequently have to use their memory to indicate the previous location. Robust deficits have been observed, also correlating with degree of hippocampal removal. More recently, this spatial memory impairment has been found to be proportionately greater than that for recall or recognition of patterns or objects (reviewed in Morris et al, 1999).

The above type of task requires observing a static spatial array, with the possibility that the spatial location can be encoded in an egocentric fashion, in relation to the bodily frame of reference. However, theories linking the hippocampus to spatial memory, which incorporate the notion of an allocentric representation (O'Keefe & Nadel, 1978; O'Keefe & Burgess, 1996), involve dynamic visuospatial processing, with movement of the participant. Accordingly, a series of studies have been conducted by Morris and colleagues (reviewed by; Morris et al., 1999), which were designed primarily to measure allocentric spatial memory. For example, Feigenbaum et al (1996) developed a computerised task, in part of a human analogue of the Olton Maze test (1977), in which a graphically represented turntable was presented on a computer screen fitted with a touch sensitive screen. A number of spatial locations on the turntable were signified by black dots. The participant had to search these locations by touching them in turn until they found the correct one, at which point it would turn green. The correct location moved to another dot and the participant had to search again to find this new location, and so on until all the dots had been found. Feigenbaum et al (1996) found that only patients with right temporal lobe brain lesions were impaired on this task.

The above study relied on rotation of the spatial array in order to induce allocentric representation, rather than participant movement. An alternative task was developed by Abrahams et al (1997), with a circular layout of small containers, place on a central table. The participant observed objects being placed into the lidded containers and then had to indicate which ones had been used and which objects had been hidden. To emphasize allocentric memory functioning, the participants had to walk round the table in between placement of the objects and memory testing. Only patients with right temporal lobe lesions were impaired in memory for location, whilst both left and right lesions patients were impaired on object recognition memory. This study has since been replicated in part using an immersive virtual reality set up, in which the participant was placed in a virtual room and had to search around a number of locations on a virtual table, the locations signified by upturned shells. Here a pronounced spatial memory deficit was observed in patients with right temporal lobe lesions.

The above studies support the link between allocentric spatial memory functioning and the right hippocampal formation. In order to explore this further our group have recently developed an Arena Task, which is a VR human analogue of the Morris water Maze (Morris, 1982) used extensively to study hippocampal spatial memory impairment in rodents. In the rodent version, the animal has to swim to a hidden platform and subsequently remember the platform location using cues around the testing room. In the VR version, the participant is placed in a circular arena, with pattern rendered walls and has to move towards a pole situated in the arena. When they arrive, the screen freezes, there is a short delay and they then re-enter the arena. The pole is then removed from the arena and they have to re-enter it and move the previous location of the pole. In order to explore allocentric memory, the re-entry point is from a different direction and they have to use the patterns on the arena wall to guide their movements. This is compared to an egocentric condition in which the entry point is the same, but the walls of the arena 'rotate' so as to force the participant to move to the location by repeating the same directional movement in relation to their own body.

In this study, this task was used in two manners: (1) A functional magnetic resonance imaging (fMRI) study was conducted in which brain activation was explored in a group of normal participants, with the hypothesis that the allocentric condition only would activated the hippocampus; and (2) to explore hippocampal formation function using this technique in two case studies in which selective bilateral hippocampal lesions caused by anoxic brain damage. The latter type of patient has been used previously to investigate the neuropsychological consequences of 'pure' hippocampal loss (e.g. Holdstock et al., 2000). Here it was predicted that hippocampal activation would be attenuated due to loss of hippocampal function.

## 2. METHOD

### 2.1 Participants

The first patient (PR), aged 30 years, acquired his brain damage through carbon monoxide poisoning. Detailed structural MRI scanning revealed selective bilateral hippocampal damage affecting principally the CA3 field, but leading to clear overall reduction in hippocampal volume. An estimate of his premorbid intelligence using the National Adult Reading Test placed him in the superior range (121). He also showed superior range intelligence, as tested using the Wechsler Adult Intelligence Scale III (full scale IQ = 133). In contrast, his memory scores on a standard battery used to test memory functioning, the Adult Memory and Information Processing Battery (AMIPB) placed him in the bottom tenth percentile. The second patient

(AC), aged 42 years, had anoxic brain damage due to status epilepticus. This again had caused selective bilateral hippocampal damage in the context of no identifiable damage to other brain regions. His predicted full scale IQ was in the high average range (111). In contrast, his memory function, tested using the Wechsler Memory Scale Revised was in the low average range overall.

The control participants were eleven right-handed male participants (Mean age 26.72, range 19-45) who were free from significant physical illness, had no history of neurological impairment or psychiatric conditions were used in the study. They were assessed for estimated general intelligence (Mean 119, range 114-123), using the National Adult Reading Test (Nelson & Willison, 1991).



**Figure 1.** The Arena task layout showing the pole in the distance and the changing view as the participant approaches the pole. Note the 'puck' around the pole. The subject uses this guide the final approach.

## 2.2 Virtual Reality Test

The Arena Task was programmed by Third Dimension Ltd using Superscape Virtual Reality software. To present the test, a Dell computer was used with a Pentium III: 450MHz microprocessor, 64 MB RAM, an 8 MB 3D AGP Graphics Card. The image was displayed via a Proxima 55100 projector onto a Perspex screen at the foot of the scanning table. GE Signa 1.5 Tesla system MR system.

## 2.3. Procedure

The appearance of the Arena is shown in Figure 1. Movement within the arena is controlled by the joystick, with a right and left movement rotating the viewpoint to the left and right respectively and forward movement producing a constant forward velocity (the Arena is a traversed by forward movement in approximately 20 seconds). For each condition, the participant has a 30 second époque in which they must reach the pole. The screen then freezes for the remained of this époque and there is a blank screen delay followed by the retrieval phase. Here the participant re-enters the arena and moves to the previous pole location, pressing a 'firing button' on the joystick to signal this location. There is a further 30 second delay and a control visual display is presented for 30 seconds, an amalgam of the Arena wall patterns.

This procedure is repeated five times for the two main conditions. The allocentric condition is presented first, in which the participant always re-enters the Arena from a different angle, and then the egocentric condition in which the starting position is conceptually the same, but the Arena walls rotated to remove any reliance on external cues to determine pole location.

## 2.4. fMRI Measurement and Analysis

Gradient recalled echoplanar MRI data were acquired using a GE Signa 1.5 Tesla system (General Electric) retrofitted with advanced NMR hardware using a standard head coil. 100 T2\*-weighted images depicting BOLD contrast were acquired at each of 16 noncontiguous near-axial planes (7 mm thick, 0.7 mm slice skip) parallel to the intercommissural (AC-PC) line; TE = 40 ms, TR = 3 s, flip angle = 90 degrees, number of signal averages = 1. Prior to time-series analysis, data were processed to remove low-frequency signal changes and motion-related artefacts. The responses at each voxel were then analysed by regressing the corrected time-series data on a linear model produced by convolving each contrast vector to be studied with two Poisson functions parameterizing hemodynamic delays of 4 and 8 seconds. Following least squares fitting of this model, a goodness of fit statistic composed of the ratio of model to residual sum of squares was calculated for each contrast. The distribution of the same statistic under the null hypothesis of no experimental effect was then calculated by wavelet-based resampling of the time series at each voxel and refitting the models to the resampled data. An experimentally derived null distribution of the goodness of fit statistic was then obtained by following this procedure ten times at each intracerebral voxel and combining the resulting data. This method has been shown to give excellent control of nominal type I error rates in

fMRI data from a variety of scanners. Activations for any contrast at any required p value can then be determined by obtaining the appropriate critical values from the null distribution. The number of expected positive pixels for the whole brain used during.

Activation patterns were obtained for each of the main époques (allocentric, encoding and retrieval; egocentric encoding and retrieval; and pattern presentation). In each case, activation was compared against the rest phase époques.

### 3. RESULTS

#### 3.1. Activation in Control Participants

The brain activation maps for the control subject group are shown in Figure 2. These show in sagittal slices the areas of activation associated with each phase of each condition. For the allocentric encoding condition a network of brain regions are activated associated with spatial memory. This includes the activation of the visual cortex (low level visual processing), the parietal cortex (spatial manipulation), the thalamus (spatial orientation) and the hippocampal / parahippocampal regions (encoding allocentric memories). For the allocentric retrieval phase the network is essentially the same, but the thalamic activation is reduced and there is no parahippocampal / hippocampal activation. The egocentric encoding condition shows a similar pattern of activation to allocentric encoding, with the exception of no parahippocampal / hippocampal activation. The egocentric retrieval phase produces essentially the same pattern of activation as the encoding phase. A further condition was the presentation of the amalgam of patterns. This produces just visual cortical activation, consistent with low-level visual analysis.

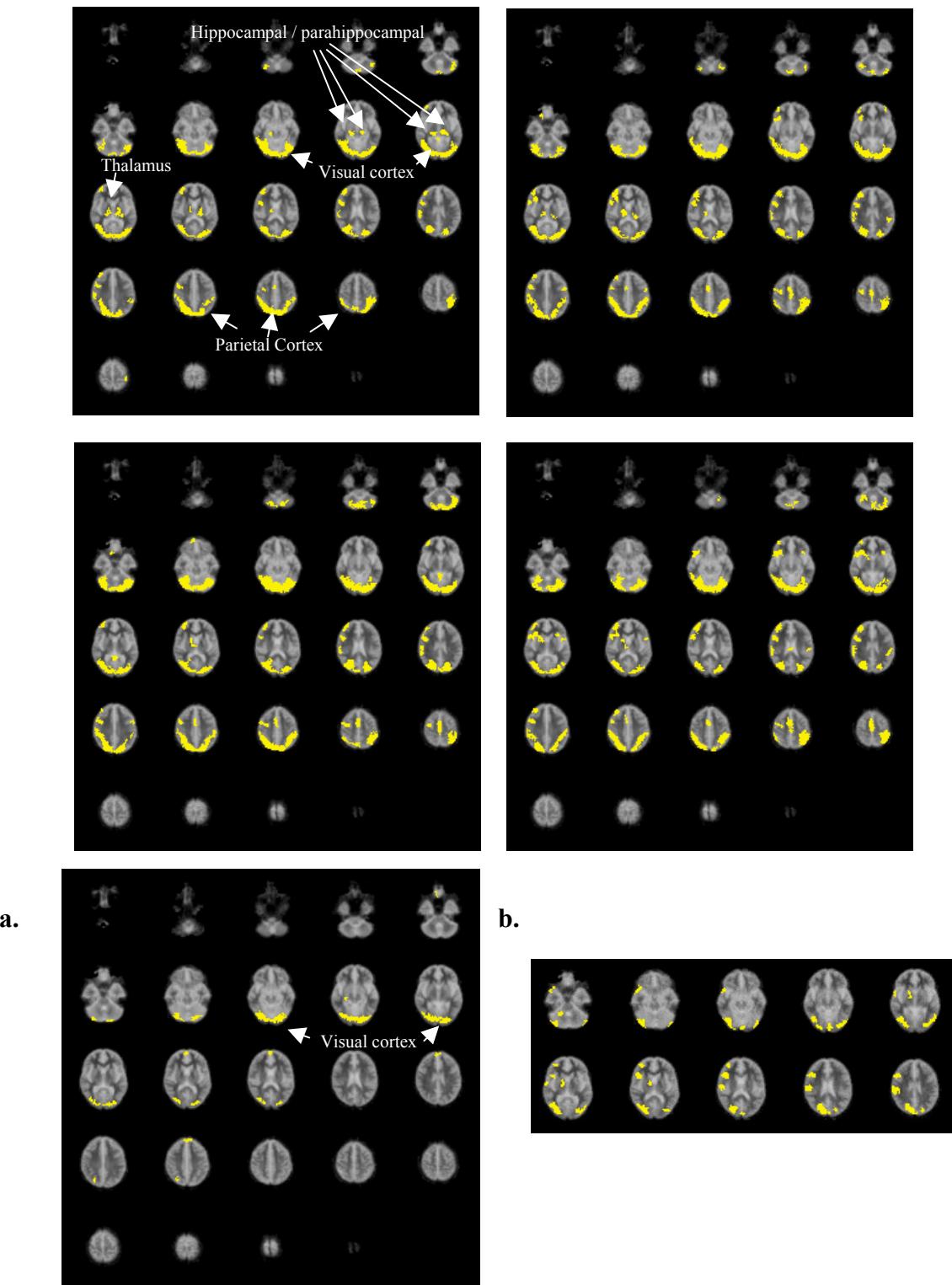
#### 3.2. Activation in the two anoxic brain damaged patients

The same analysis as for the control participants was conducted, but using the two anoxic brain damaged patients and for the encoding phase of the allocentric condition only. The brain activations are shown in Figure 2. These show a similar activation pattern as in the controls, but without hippocampal / parahippocampal activation or thalamic activation.

### 4. DISCUSSION

The study used fMRI combined with virtual reality in order to investigate brain activation associated with allocentric spatial memory. This revealed a network of activation incorporating key neuronal structures, all of which have previously implicated in this function. The network can be considered in a hierarchical fashion, starting with low level visual processing in the visual cortex. Information follows the ventral route into the temporal lobe for pattern recognition and simultaneously via a dorsal route to provide processing of spatial information. This is combined to form an allocentric representation of location and the encoding process takes place in the hippocampus. The hippocampal formation interacts with the thalamus, which is involved in whole body orientation to external stimuli. The lack of hippocampal formation activation with the egocentric condition suggests that this type of spatial memory is not so reliant on this structure, insufficient to produce activation in the current experiment. This is in accordance with the O'Keefe and Nadel (1978) theory about the hippocampus, that is storing viewer independent spatial information in the form of cognitive maps.

A finding of the current study is that the hippocampal activation was bilateral and also extended into the parahippocampal gyrus. The bilateral effect is at odds with the results of studies of patients with unilateral brain lesions and suggests that right hippocampal damage specifically affects spatial memory (Smith, 1989). This apparent conflict in findings may be accommodated if it is assumed that there is a difference between activity and vital function in the brain. For example, it is possible that spatial information enters the hippocampal based memory system in the right hemisphere. A lesion in the right temporal lobe can effectively sever this input into the system and so produce spatial memory impairment. Nevertheless, in a normal brain, spatial information entering the system may produce bilateral activation. The finding of parahippocampal and hippocampal activation is frequently reported and represents the close coupling of these structures in terms mnemonic processing. Additionally, this activation was shown to be in the posterior hippocampus and this is consistent with rodent findings, where lesions of the equivalent dorsal hippocampus is shown to produce spatial memory impairment.



**Figure 2.** The brain activation maps for normal participants. These show sagittal slices through the brain. Top left: allocentric encoding; top right: egocentric encoding; bottom left: allocentric retrieval; bottom right: egocentric retrieval. Asdditional panels (a) show pattern activation and (b) activation in the two anoxic patients

The study also conducted fMRI recording of encoding in two patients with anoxic hippocampal brain lesions. These lesions on structural MRI are shown to be very specific and the lack of hippocampal activation reflects the observed brain damage. This is further supported by activation of the rest of the network, including the visual cortex, thalamus and parietal lobe. The finding is also consisting with a

previous study by Holdstock et al (2000), who showed allocentric spatial memory impairment in a single case study who had bilateral hippocampal damage. Use of virtual reality, in which the participant has to interact with the environment and where the visual cues are controlled carefully shows that the deficit can be extended to demonstrate lack of hippocampal activity, and so demonstrate directly the neuronal effects of structural damage.

This study illustrates the potential use of VR combined with fMRI, firstly to identify the network of neuronal structures involved in a dynamic task and, secondly, applied to patients with focal brain damage. Future studies should be able to exploit this approach in terms of rehabilitation, and this would apply to neurorehabilitation techniques, pharmacological interventions and even neural transplant, where reconstitution of function could be measured using functional neuroimaging. VR provides techniques more akin to real life, but also with the advantages of computerised control, a suitable approach for combining with brain activation measurement.

## 5. CONCLUSIONS

The study has used VR to highlight a network of neuronal activity associated with a dynamic spatial memory task, consistent with the cognitive mapping theory of hippocampal involvement in spatial memory. It also shows how structural damage to focal brain regions can be shown to lead to functional disturbance, measured at the neuronal level. VR provides a mean of executing dynamic and interactive tasks during functional neuroimaging and has the potential to be used in this fashion to the assessment of neurorehabilitation outcome

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# Three applications of virtual reality for brain injury rehabilitation of daily tasks

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## ABSTRACT

Part of the process of rehabilitation after a brain injury is the relearning of various daily tasks such as preparing food, managing finances, getting from one place to another and so forth. These tasks require learning on all levels from physical to cognitive. Remembering a PIN code for a bank card, for example, can become automatic and 'in the fingers' after much repetition. However, other tasks require a certain cognitive process, for example, procedures must be followed, quantities estimated, numbers of items remembered or dangerous situations avoided. Even in these cases, repetition of the task many times can help fix the important aspects in the mind. This paper describes three applications of a Virtual Reality based method of rehabilitation which are a part of a larger project to investigate the potential and pitfalls of Virtual Reality technology as a complement to physical training in Brain Injury Rehabilitation. Virtual Reality has the advantage of providing a safe, controlled and highly repeatable environment that a patient can experience in a relaxed manner before having to encounter the potentially dangerous or stressful real environment. The three applications considered here are: kitchen work, an automatic teller machine (ATM) and finding ones way in a complex environment.

## 1. INTRODUCTION

The project 'Virtual Reality for Brain Injury Rehabilitation' at Lund University, Sweden is now entering into its third year and has produced many interesting results. The project has had three main goals:

- To investigate usability issues of VR technology for people with brain injury.
- To examine the issue of transfer of training.
- To develop three different applications of VR for training of daily tasks.

The initial stages of the first goal have been reported in Davies *et al* (1999) and Lindén *et al* (2000), however the final results are still being analysed. From this stage of the project, the most suitable input devices and methods of design of the Virtual Environments (VE) have been chosen. Further, implications for usability of those decisions have been assessed (if the reader is interested in further details and results from these studies, please contact the leading author; these results will be duly published once analysis is complete).

The second stage, that of transfer, is also still being investigated and is being considered separately for each of the Virtual Environments being developed in stage three. This paper is intended as an overview of the work and deals primarily with these Virtual Environments, the tools used, and summarises the studies so

far performed and the results so far obtained. Comments are also made about usability and transfer as appropriate.

## 2. NAVIGATION AND INTERACTION

From the usability studies, the input device for moving around a VE (navigation) has been chosen to be a large programmable keyboard with arrows drawn on its surface to give three degrees of freedom (ie six possible directions of movement; move forward, move back, turn left, turn right, move left and move right). A joystick caused the subjects in the usability tests to become disorientated whereas a keyboard, though slower, provided better control. Two degrees of freedom was found to be adequate, three allowed for more precise movement in confined spaces, more causes confusion. Nevertheless, more complex navigation devices might be suitable for patients with experience using them, for example, from playing computer games.

Interaction with objects requires a separate device (to reduce cognitive load and device complexity). A touch-screen allows direct contact with the objects being moved or used, but not all people have sufficient dexterity. A mouse is cognitively more abstract, but physically easier for some, and other pointing devices may be necessary for people with physical disabilities. Our studies have suggested that people with very little computer experience manage mouse movement, clicking-to-activate, and even drag-and-drop without problem, in fact, they expect these capabilities and can be confused when such is not possible.

Furthermore, a 'carrying-hand' object (see fig. 1(a), bottom right of picture) that follows the viewpoint can be used to place objects on when moving from one part of a VE to another. This is expected to reduce cognitive load and physical dexterity requirements (having to hold a finger on the screen at the same time as navigating). Usability tests suggest that the concept is easy to understand and was in fact spontaneously used by some of the subjects without instruction into its function, but the form, size and location could be refined.

In the applications described in this paper, therefore, the primary navigation device, (where one is needed) is a large keyboard with three degrees of freedom and the primary object interaction device is a touch-screen and allows click-to-activate, drag-and-drop and a carrying-hand where appropriate. Exceptions to this are noted and are usually related to programming limitations.

## 3. THREE APPLICATIONS

Three representative training tasks have been chosen in consultation with Occupational Therapists for development into VE applications. The selection was based on usefulness in the rehabilitation process, suitability for implementation using VR, to give a range of task types and to test different forms of VR tool. These tasks are; kitchen-based training (eg. brewing coffee, laying a table); using a vending machine (in this case, an Automatic Teller Machine (ATM)); and finding ones way in a complex environment.

### 3.1 Task 1 – Kitchen, using *WorldUp*

A virtual kitchen has been developed as a test-bed for each of the three goals. This kitchen is a replica of a training kitchen in the same area. This has been chosen both as a suitable environment to test usability of input devices and programming methods and for investigation of transfer of training between the virtual and real kitchens. The tasks to be performed in the kitchen are; brew coffee, fry an egg, make toast and lay the table. These have been chosen from the standard suite of training tasks (Fischer, 1995) used by the Occupational Therapists in the real kitchen.

In the kitchen, it should be possible to perform the tasks in whatever manner the user chooses. Different learning strategies can be applied, both learning by trial-and-error and error-free learning. Assistance in performing the task in the correct way is provided by the Occupational Therapist though some in-built help may be available later. If the user becomes sufficiently confident with the tool, they may be permitted to use it independently, though a completely self-sufficient task environment is not presently the goal.

As previously mentioned, three degrees of freedom navigation is provided via a special keyboard and interaction via a touch-screen. Click-to-activate, drag-and-drop and the carrying hand are possible.

An important feature of this environment is the stereo sound effects. Not only should objects look more-or-less as in reality, but they should sound right also. Previously (Davies *et al*, 1999), we have found that realistic sound can compensate for less-than-realistic visual effects (for example, pouring liquid is

complicated to model in VR, but playing a sound encourages the user to believe the liquid is flowing anyway when the visual effect is missing). Furthermore, sound provides clues to the user about the status of various objects. If the tap is on, running water is heard. One part of the procedure is to remember to turn off the tap, and attention to audio cues is thus vital. Or, when the toast is ready, it pops up with an appropriate sound. Thus, even when not in the visual field, the toaster notifies the user of its status and they must take appropriate action. Inclusion of olfactory feedback is also appealing, for example the smell of burning toast, but beyond the scope of this project.



**Figure 1.** The virtual kitchen (a) and the real kitchen from which it is modelled (b).

The tools used in the development were: digital camera and scanner for obtaining textures of objects like packets, pictures on walls, outside the window and fronts of various kitchen appliances; Adobe Photoshop® for texture editing and refinement; digital camera with mpg recording capabilities for capturing sound effects; Adobe Premier® for isolating required sounds and saving in correct format (an advantage of using a digital camera for sound recording is that one has a visual cue as to what the sound actually is); AutoCAD® and 3DVis® for model building and Sense8 WorldUp® as the Virtual Reality design and visualisation tool. A special driver was also required for WorldUp for reading from a joystick with more than two degrees of freedom. For distribution, all that is required is the WorldUp Player, the joystick driver and the VE files.

The main complication in this environment is the desire to make it as natural as possible so that the user can perform the required tasks in whatever manner they like. This necessitates an object-oriented programming approach with each object (such as a coffee pot) having certain attributes and behaviours – what is to happen when filled with water and heated, for example. One also needs to consider which behaviours are sensible to program. Should we program the outcome of boiling the coffee pot dry, for example? Decisions as to what effects to include are taken in consultation with the Occupational Therapists and in consideration of programming time.

Usability studies have been performed to investigate the best way to navigate and interact with the VE, as mentioned above. These were performed on people at the hospital with little computer experience. The level of usability for people with brain injury has yet to be assessed. This environment will be the main test-bed for transfer of training studies since it is a controlled environment with the real version close by. Patients will be asked if they wish to take part; each will form an individual case study. Training in the VE will be prior to training in the ordinary kitchen and not as a substitute for obvious ethical reasons.

### 3.2 Task 2 – Service and Vending Machine, using WorldUp

The virtual kitchen is a large and complex environment where the user must move around between different places in order to carry out the tasks. Thus an input device for navigation must be used (and be usable). Another situation where VR was expected to be useful (Davies et al, 1999) is in training to use an Automatic Teller Machine (see also Wallergård *et al*, this volume). Normally, this task is carried out at a local machine, but this is not practical for repeated training. Modelling the task in VR allows for repeated training before the real machine is encountered. Codes can be learnt and exceptional circumstances experienced (such as entering the wrong code three times causing the machine to swallow the card). For this task, the user need not move around, they must simply operate the machine. The view zooms in and out as appropriate (so no navigation device is required) and interaction with the machine is with a mouse or touch-screen.

Two prototypes have so far been developed (fig. 2). The first to investigate the feasibility and complexity of developing an ATM in VR and for testing aspects of usability with people with brain injury (Wallergård *et al*, 2001). The second to extend the concept to other forms of service machine and to develop a more general framework to allow the construction of almost any such machine from a number of base components. This would allow service machines from the patient's own environment to be quickly constructed thus ensuring greater usefulness and situational training with those machines the person will actually encounter.



**Figure 2.** Two functional prototype Service Machines modelled in Virtual Reality.  
(a) is an Automatic Teller Machine, and (b) is a local train ticket machine.

The tools used in the construction of the VE are the same as for the kitchen. One problem that occurred was in obtaining realistic texture-photographs of an ATM as this takes time and can annoy people actually trying to use the machine. Furthermore, many surfaces are made of shiny metal which gives poor quality textures with reflections. The first machine developed using the second prototype (fig 2(b)) uses textures obtained from the website for the service machine owners. This gives a much better quality object, though with a somewhat matt look, but avoids the above problems.

Further details and results from usability tests can be found in Wallergård *et al* (this volume).

### 3.3 Task 3 – Way finding, using HalfLife

Both of the previous tasks involve single rooms or single devices. For the third application, it was decided to increase the scale and consider an entire building. A problem that many people have is finding their way from one place to another. Standard training involves travelling the route and committing to memory key features in order to remember which way to go. It was thus decided to develop an environment that patients would need to learn and of a sufficient complexity to be non-trivial.

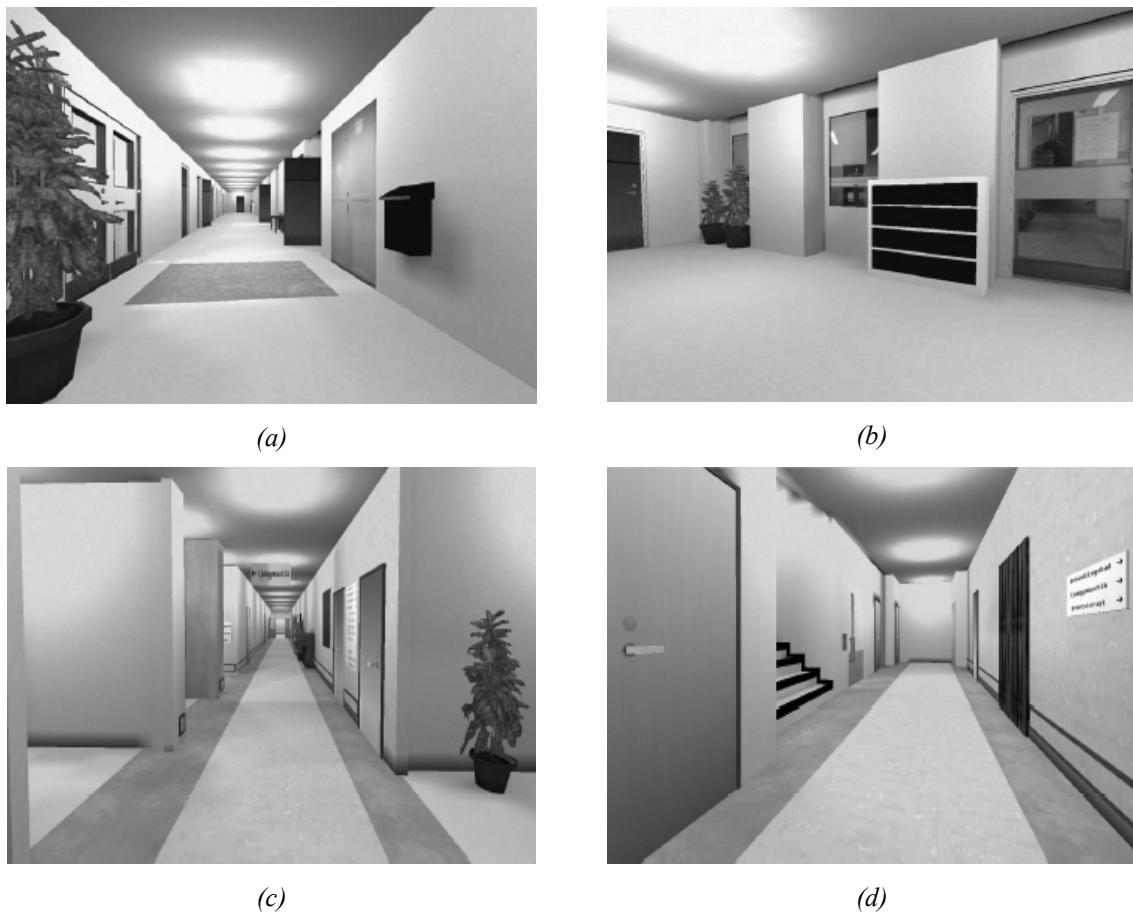
The environment chosen was the rehabilitation hospital itself, and the route from the Occupational Therapist's area to the family hotel. The hospital is spread over two buildings built on a hill with interconnections resulting in confusing changes in levels. The route is one that is not often traversed by the patient, but may be of interest. It also requires moving along several corridors, turning at the correct points and moving between floors (either by elevator or stairs).

Two prototypes have been developed using the tools Worldcraft, for environment design, and Wally, for texture management to produce a VE that runs in HalfLife® (Löfgren, 2002). Textures have been obtained with a digital camera and modified in Adobe Photoshop®. Early in the project, it was decided that a tool other than WorldUp should be used, partly to give experience, and partly as 3D Game Engines are particularly well suited to the building of long corridor interior environments. The construction tools can be obtained online and are standard for the development of 3D games using the HalfLife engine. They are of a professional quality and similar in many ways to standard VR development tools.

The environments generated have something of a game-like quality, however, various effects make the environment seem quite realistic, such as; automatic collision detection with walls and objects, realistic lighting effects (with shadows), walking action – including climbing stairs and object collision detection, and truly surround-sound effects. Many other features, such as monsters and guns typically found in 3D games are optional for a hospital setting.

In the design, several usability goals were made:

- The VE must be relevant, that is, the person must be able to use it to find their way and remember it. It should help the Occupational Therapists to notice what the patients observe in the environment.
- The VE must be efficient, that is, movement should flow easily and the user should not become stuck on unseen obstacles (such as door jambs). The Occupational Therapists should be able to easily follow what the patient is doing.
- A positive attitude to the VE is desired since this would make the patient want to try the VE, and benefits should be apparent to the Occupational Therapists so they see some purpose in using the tool.
- The tool should be easy to learn. Short-term memory problems could mean that the patient may not easily remember how to use a complex interface, thus it is ideal if they can simply sit at the computer and walk through the VE without any significant difficulties.



**Figure 3.** Virtual Environments for learning to find one's way. (a) and (b) are from prototype one – a corridor at the university, (c) and (d) from prototype two – a corridor from the hospital.

The task of way-finding is complex and depends on subconscious and conscious cues for a person to establish both where they are and the direction to take. In the development of a VE, it is important to include enough cues (objects, colours, signs, etc.) so that the person can recognise the real environment after using the virtual one. The problem is knowing which cues to include; it would be prohibitive to include everything, but it can be difficult to know what people will actually notice. Furthermore, different people will notice different things, depending on interest. For these studies, as many conscious cues as possible are included such as signs and objects that the Occupational Therapists usually point out. Colours, floor and wall materials, lighting, and of course, general shape of the environment are made to be as close to the original as possible. Other objects of significant size are included, but many small or mobile objects are not.

Two prototypes were created. The first, a corridor at the university, was designed with the purpose of establishing both the most usable and visually pleasing means of constructing the VE within the technical

limitations of the Halflife environment. Issues such as means of navigation (with mouse, keyboard, or both), the level of realism required for surfaces and objects, and how to represent non-modelled spaces in a realistic manner were investigated. Further, we were interested in whether people familiar with the real environment would recognise the computerised version, and if not, why not. This was tested on members of the university department familiar with the real corridor and people unfamiliar with the environment from the hospital. They were instructed to go to certain places in the corridor, observed during the tests and interviewed afterwards.

The second prototype was of the route at the hospital described above and included elevators which could be used if desired. This was tested with five subjects from the hospital with experience of people with brain injury and varying computer experience. They had to find their way in the VE, thinking aloud and making observations on the way and were recorded for later analysis. Afterwards, they were interviewed. More exact details of the tests, subjects, interviews and analyses can be found in Löfgren (2002).

#### 4. A USER-CENTRED DESIGN METHODOLOGY

The overall method for the project has had the user needs at the centre – ultimately, the tools developed must be usable by people with brain injuries in the rehabilitation process and be useful for the people working with them (such as Occupational Therapists and family).

Each application has been developed with a user-centred design approach. In each case, there are two primary user groups; the person with a brain injury who is to use the tool, and the Occupational Therapist(s) responsible for the rehabilitation program. The former must be able to use the equipment without undue cognitive loading, and the latter must be able to set-up and run the VE as well as gather meaningful data about how the rehabilitation is progressing.

In all the applications, step one has involved gathering information and learning about the task to be programmed. This has meant extensive discussions with Occupational Therapists and visits to the rehabilitation hospital wards. At this stage, the Occupational Therapists act as expert representatives for the people with brain injury. Much of the fine-tuning to the VEs is performed on-site to give easier access to patient expertise and the real environments. Furthermore, staff at the hospital have been used often as subjects in early testing stages, and their comments are always welcomed and provide useful insight into whether we are on the right track or not.

In step two, low-fi or simple computerised prototypes have been made and tested with members of each user group. Again, the Occupational Therapists act as expert representatives for people with brain injuries. This is due to the difficulties involved in using standard testing methods with people with brain injury who may have difficulty concentrating on multiple tasks (such as using a program and thinking aloud), cannot easily abstract from a low-fi prototype, have trouble following instructions or find it hard to manage an interview or questionnaire. The current kitchen tool was preceded by a simple coffee-making environment (see Davies *et al*, 1999), the ATM by paper prototypes and the hospital corridors by a simpler corridor at the University.

From the results of steps one and two, successive computerised prototypes have been developed and tested with real users (Occupational Therapists and people with brain injury) resulting finally in tools which can be said to be usable by the intended users for the intended tasks.

### 5. RESULTS

#### 5.1 Task 1 – Kitchen

The virtual kitchen has been extensively tested as part of investigating usability issues of the VR technology. Results indicate that a specially designed keypad is most understandable for navigation, though a joystick can be beneficial for expert users. Furthermore, two degrees of freedom can make navigation complicated, but three degrees (being able to walk sideways as well) can make it easier to become lost. Both mouse and touch screen have been considered for interacting with objects; results are still being analysed. Moving objects by drag-and-drop was spontaneously understood by most subjects, though almost all expected objects such as cupboards and drawers to be activated also by a click-and-drag action (in fact, only a click was required). For some, having a hand to carry objects in was considered obvious, others managed without. The tasks to

be performed within the environment (brewing coffee, making toast, frying an egg and laying the table) are still being programmed and thus no further results can be presented here.

### 5.2 Task 2 – Service and Vending Machines

The virtual ATM built on results from the virtual coffee machine tests (Davies et al, 1999) and is similar in that the user need not worry about navigation – the computer determines from the current state of the task which view is most suitable. In the evaluation, some of the subjects had problems with the interaction method, some misunderstood the virtual representation of the ATM interface and visibility of small objects such as buttons was problematic. However, for some, the virtual representation was so encapsulating that they unconsciously tried to grab the money – this suggests a high degree of presence.

### 5.3 Task 3 – Wayfinding

Testing the first prototype produced the following results:

- The corridor was not immediately recognised by a couple of the subjects.
- Textures from photographs were considered indistinctive.
- The most effective way for showing a non-modelled room was to past a picture from the real room on a flat block placed in the doorway, though odd viewing angles can mean strange perspective views.
- Windows can be mistaken for mirrors or paintings..
- The plants were considered good, as well as an extension of the corridor that was not modelled, just photographed.
- The mouse for navigation was difficult. Navigation with just the keyboard was considered much easier.
- The overall attitude was positive.

The tests with the second prototype produced the following:

- The first part of the corridor was recognisable, though some subjects thought it narrower than in reality.
- The paucity of objects was commented (the real corridors are much more cluttered).
- The interaction with the elevator was difficult and lacked feedback (the user has to wait till the door opens, enter the elevator before it closes again, face the button panel, and then press a key on the keyboard – this is standard for games, but not very intuitive).
- The elevator doors could open when it was in motion, and opened and closed too quickly. One of the elevators in reality doesn't have self-opening doors but did in the VE. Two of the subjects experienced some dizziness in the elevators.
- The second floor was mostly unrecognisable near the entrance way to the building. This was thought due to the fact this area is glassed-in with views of the outside, which were not present in the VE.
- Some landmarks were missing, such as 'the janitor's coat', and some colours were not correct. Lighting was not considered realistic.
- Navigation was complicated by the viewpoint becoming stuck on some door openings.
- The signs were useful for people not used to the hospital (though inadequacies in the sign-posting in the real hospital were discovered in the studies).
- Overall, the attitude was positive, and the subjects thought that a remade version might be useful for rehabilitation.

Further work is now being performed to produce an improved prototype based on these results which can be tested with people with brain injury in real way-finding situations. Of particular interest will be what visual cues are required by these users, and whether they experience the virtual corridors as being the same as the real ones. Furthermore, the users will not already be familiar with the real environment, so may not be as critical to level of realism so long as the cues they have learnt in the VE actually exist and are recognisable in the real world.

## 6. DISCUSSION

Different tools have been used in the different applications. The more ordinary VR development tool WorldUp has been found to be useful for general purpose VEs and the development of complex systems which require interaction from the user. Halflife and associated tools has produced pleasing results for large

environments which one can wander around in, but is difficult when interaction with objects is required. However, the future Virtual Reality systems may well be based on such game-engine technology, since the rate of development is very rapid whilst the price is very low.

The work reported in this paper is still in progress and aspects about usability and transfer of training are still being analysed or are yet to be tested. However, the development of these applications has progressed well, and the various tools chosen have been found to be adequate for the design of VEs for rehabilitation.

Nevertheless, the time required to develop a new task from scratch could well be prohibitive for long term usage in rehabilitation contexts. The main difficulty is the programming of object behaviours; every minute reaction to an action taken with an object has to be considered, modelled and programmed. One possible solution to this is to make reusable modules, as is being done for the service and vending machines part of this project. Even so, considerable remodelling and programming of the executive functions must still be performed. In the kitchen, it may also be possible to work with predefined modules to build up any kitchen layout, however, making an exact replica of, say, a patient's own kitchen will still require much time and expertise. Similarly, creating objects that look realistic (and are recognisable) can take much time, either in the modelling of the object in a CAD package, or in taking pictures from reality, modifying these to improve quality and using these as textures on simpler objects.

It can be concluded that VR will very likely become a valuable training technique, and many others have also found it to be beneficial in various cognitive training tasks. However, it has always been maintained that it can, at best, be a complement to existing rehabilitation methods. This view is repeatedly reinforced by discussions with Occupational Therapists and other medical experts since VR by itself misses a vital physical component of the training. Plans are being made, however, to couple Virtual training with real training in so-called Mixed Reality systems. Similarly, further work is required to speed up the development process, and perhaps even make it possible for Occupational Therapists and care-givers themselves to develop new virtual training environments, or at least adapt existing ones to local conditions. It may even be worth considering the development of a standard for interconnection of virtual object modules and the creation of an open-source library of objects available to all.

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# **Virtual reality investigation of strategy formation, rule breaking and prospective memory in patients with focal prefrontal neurosurgical lesions**

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## **ABSTRACT**

Planning and organisational ability was investigated in 35 patients with prefrontal lesions, using virtual reality (VR) to mimic everyday activity, but in a laboratory setting. A multi-componential VR procedure, the Bungalow Task was developed to test strategy formation, rule breaking and prospective memory. The task involved simulation of decision-making whilst a participant moved around a virtual bungalow, selecting furniture for removal according to specified instructions, and various aspects of prospective memory were tested. Significant strategy formation and rule breaking impairments were observed and additional time and activity, but not event based prospective memory impairment observed. The study demonstrates the successful use of VR as a neuropsychological tool for investigating executive functioning in an ecologically valid fashion.

## **1. INTRODUCTION**

Virtual reality (VR) approaches to neuropsychology offer the prospect of simulating real life activities and this has a number potential uses; for example, assessing neuropsychological impairments in a fashion that bridges the gap between deficit and everyday disability; and also engaging patients in neuropsychological rehabilitation in a 'trial' fashion, so as to build up behavioural skills without the initial complication of engaging the patient in hazardous activity. Despite this, there have been relatively few developments in this area and there are many VR procedures could be developed to benefit this field.

One such area is to assess executive functioning in patients with various forms of brain damage. The term 'executive functioning' refers to the sequencing and organisation of behaviour, and incorporates a variety of cognitive processes, including planning, strategy formation and mental flexibility. The neural basis of such abilities have been strongly linked to the prefrontal cortex, with damage in this area resulting in respective behavioural impairment. Traditional tests of executive functioning have been developed and these are used in the routine assessment of patients.

Nevertheless, there is a growing consensus for the need for tests of executive functioning that are closer to 'real world activities' if they are to be useful in predicting patient disability. This was highlighted initially by Shallice and Burgess (1991), who investigated three patients with frontal lobe damage who performed normally on established executive functioning tests but demonstrated disorganised behaviour in everyday life. To try to capture the latter experimentally, they designed the Multiple Errands test in which they took their patients into a city street and required them to conduct a number of errands. For example, they had to buy certain items such as a brown loaf and a packet of fruit pastilles. More complex tasks were also included, such as obtaining the necessary items to send a postcard and certain fact finding errands. They also built certain rules into the test, such as having to spend as little money as possible. This test proved very sensitive to executive impairment in these patients, a finding that has been replicated by Goldstein et al (1993) in a single case study of a patient with a focal frontal neurosurgical lesion. Such experimental studies have also

given rise to standardised tests such the Zoo Map test and the Modified Six Elements test, which are now in routine clinical use (Wilson et al., 1996), but which try to simulate everyday activity through laboratory tasks. For example, the zoo test involves presenting the patient with a map of a zoo and giving them the instructions that they have to trace round the zoo (using a pen), visiting certain locations and not repeating some of the routes.

Other approaches have focused specifically on planning ability. This includes the Virtual Planning Test developed by Miotto and Morris (1998). This is neuropsychological test in the form of a board game in which participants are required to carry out a number of actions within four fictional days. They have a planning board, with various activities arrayed in front of them, each activity presented as action instruction on a 'chip.' For each day, they have to select four activities and by the end of the four days they have to have completed a number of target activities as specified on a cue card. To make the task more akin to everyday life, some activities have to be completed at or by a certain time within the period; some relate to a fictional trip abroad at the end of the four days, with others not related to this trip; some are preparatory and have to be completed in order to start other activities. Additionally, distracter times were provided to lure the patients away from the required activities. This task showed an overall impairment in the efficiency of planning in a group of patients with focal frontal lesions. It also showed they were prone to fail on more isolated activities and select distracter items which were related more immediately relevant to the patients current context.

The development of such tests has created a dilemma in terms of tasks design. If the task is made interactive and involves real world activity, such as the original Multiple Errands test, it can be too long and costly to administer, and is not possible to standardise other than for local use. On the other hand, if the tasks are simplified into the form of paper and pencil or board games, they potentially lose their degree of ecological validity and, possibly, sensitivity to neuropsychological disability. Virtual reality procedures may help solve this dilemma by bringing real world tasks back into the laboratory.

This paper describes the use of such an approach to investigating planning and organisational ability in patients with focal frontal lesions. The task, termed 'the Bungalow' is a virtual reality construction of a four-room bungalow, which the participant can navigate around with the aid of a joystick. The participant is given a scenario in which they are the imaginary removal person and have to collect furniture in specified manner. The task was developed specifically to measure planning ability in a way that tapped into certain key aspects. This included:

- (1) The ability to develop strategies: Such ability increases the efficiency of task completion and often occurs spontaneously on tasks that can benefit from the use of strategy. Frontal lobe patients have been shown to have strategy formation deficits on a variety of procedures (eg. Owen et al., 1990; Miotto et al., 1996);
- (2) The ability to follow task rules: Rule breaks are a common feature of executive dysfunction and have been shown to occur on various neuropsychological procedures, including the Multiple Errands task described above;
- (3) Prospective Memory: Remembering to execute activities at the appropriate moment is a key aspect of everyday executive functioning. This involves the laying down of markers, which are then used to 'trigger' activities at the appropriate time. Hence prospective memory is an integral aspect of the execution of plans. Patients with frontal lobe damage have been shown to be impaired in this function (Coburn, 1995).

As will be described below, these different aspects can be incorporated into one overall test, whilst maintaining the complexity and naturalistic aspect of a virtual reality test. In order to validate such a task, it was tested on a large group of patients who had undergone frontal lobe neurosurgery and where, in the past, similar cohorts of patients have shown specific neuropsychological deficits relating to executive functioning (Morris et al., 1997a; b; Miotto et al., 1996; Miotto and Morris, 1998).

## 2. METHOD

### 2.1 Subjects

35 patients who had undergone prefrontal lobe neurosurgery were included in the study. Sixteen patients had lesions restricted to the right frontal lobe (males and females), fourteen had left-sided frontal lesions (males and females), and five underwent bifrontal removals (males and females). In terms of the etiology, in the

right group there were eight cases of resections for treatment of pharmacologically intractable epilepsy, six cases of tumour removal (four meningiomas, one carvenoma, and one metestatic tumour), and two cases of anterior communicating artery (ACoA) aneurysm clippings subsequent to rupture and subarachnoid haemorrhage. In the left frontal group seven cases had undergone neurosurgical intervention for pharmacologically intractable epilepsy, six had tumours removed (two cases of meningiomas, one astrocytoma, one ependymoma, and two oligodendrogiomas II), and one patient had a lesion due to multiple aneurysms. The cases comprising the *bifrontal* subgroup had all undergone neurosurgery for the removal of meningiomas. They were matched approximately for age and National Adult Reading Test estimated IQ with a control group of 35 subjects (respectively: Age Frontal: mean = 42.2, S.D. = 12.7; Controls: mean = 42.3, S.D. = 12.3; IQ Frontal: mean = 106.8, S.D. = 11.2; Controls: Mean = 108.4, S.D. = 10.7).



**Figure 1.** The Bungalow Task showing hallway (top) and four rooms (bottom four panels).

## 2.2 Virtual Reality Test

The Superscape VRT software package was used to construct the virtual environment and programmed by Third Dimension Ltd, UK. The test run a on PC fitted on a Vivitron Monitor and a Microsoft Sidewinder joystick. To move within the environment of the task, lateral movement of the joystick produced rotation of direction and forward or backward movement, a respective forward or backward locomotion.

## 2.3 Procedure

The procedure, termed the *Bungalow Task*, consists of a virtual reality representation of a bungalow, with four main rooms and a hallway (see Figure 1). The participant is told that they are a 'removal' person and that they have to enter the bungalow and select furniture or miscellaneous items that have to be moved to another house. A number of rules are provided that dictate the manner of removal. Specifically, the participant has to collect the items for a particular room in the new house first (the lounge). The items for this room may be distributed around the different rooms of the bungalow, so the participant has to go through them in turn. They then have to repeat the process for a different room (the dining room) and so on until all

the rooms in the new house have been considered (nursery, kitchen, music room, study, bedroom and hallway). The participant moves around the bungalow, controlling their movement with the aid of the joystick and selects items by pointing to them on the Monitor, at which point they disappear.

Built in to the test are a number of tests of prospective memory. This includes: (a) *Activity related*: Here the participant has to remember to shut the front door on entering the bungalow and they should always shut the door when they exit room two; (b) *Time related*: They are told that a van is coming to the front door to take the selected furniture. The 'doorbell' is not working, so they should visit the front door every five minutes. They are provided with a clock and updated time of arrival of the van for every five minutes; and (c) *Event related*: Arranged round the rooms are specific items of furniture that contain glass. When encountered, these should not be selected for removal but should be labelled with a 'fragile' notice.

To facilitate memory for the instructions, the participants are provided with a cue card that summarise the instructions. Additionally, to ensure understanding, the participants had to explain back to the experimenter the rules of the procedure and seek clarification where necessary. There was no time limit for the test, but the overall time taken to complete was recorded. In all, 31 items were positioned in the bungalow, including the 'fragile' and 'non-fragile' items.

#### 2.4 Measures

The task has two overall measures, the time taken to complete the instructions and the number of rooms visited. In addition, there were measures of strategy formation, rule breaking, strategy formation and prospective memory as follows:

**Strategy Formation:** Piloting of the task revealed that the pattern of room search follows a set sequence or strategy. The dominant form of this is to visit rooms 1, 2, 3 and 4 in order collecting all the furniture for one category, and then going through the rooms again in this order for the next category, until all have been completed. In addition, a different search path was identified in some participants, with the order rooms 1, 3, 2 and 4. In order to quantify strategy formation, the search path was scored according to the degree of displacement from either the 1,2,3,4 or 1,3,2,4 sequences, with three points given for the zero displacement. The data were scored according to both search path models and the maximum score obtained by a subject used as the measure of strategy formation.

**Rule Breaking:** This relates to failing to select the categories of furniture in the right order, as specified by the instructions and the cue card. To obtain a score, a point is given every time a category is followed by the correct one, the measure having a maximum score of seven. The order of categories of furniture collection is obtained by following the series of responses and ascertaining when the type of furniture collected switched to a new category. Additionally, two types of intrusion errors were recorded, namely, going back to a category when this had already been attempted either during the series of categories or when all the categories had been used. These types of errors are referred to respectively as Intrusion Error types I and II.

**Prospective Memory:** For these measures, the following scoring systems were used: (a) *Activity related*: A point was awarded if they succeeded in shutting the front door on entering the building. For the requirement to shut the door when exiting room 2, a point was awarded when this happened and the total score divided by the number of times room 2 was entered, with the result multiplied by 100 obtain a percentage: (b) *Time related*: Here, the target time for opening the front door was subtracted from the time they reached it, with a positive value indicating the amount of time they were late and a negative score the degree to which they were early. Additionally, this data were unsigned to obtain an overall indication of accuracy irrespective of being later or early: (c) *Event related*: The number or times an 'fragile' item of furniture was labelled was recorded and divided by the total number of furniture items that were either labelled or selected for collection.

### 3. RESULTS

Table 1 shows the total time that the patients and controls took to complete the bungalow task, indicating that there was no difference overall. In contrast, the patients visited significantly less rooms ( $t(51.09)=4.27$ ,  $p<0.001$ ).

Table 2 provides the rule breaking data. A non parametric analysis showed the frontal group made significantly more errors than the controls overall ( $\chi^2=13.03$ ,  $df=3$ ,  $p <0.01$ ). There were also significantly

more Intrusion Type I errors ( $\chi^2=15.58$ ,  $df=3$ ,  $p=.001$ ), but no difference in Intrusion Type II errors, these type of errors being infrequent.

**Table 1.** Total time taken and number of rooms visited (standard errors are given in brackets).

	Frontal Lobe Patients Mean (S.E.)	Controls Mean (S.E.)
Total Time	19.73 (1.27)	20.52 (1.25)
Rooms Visited	20.46 (1.55)	27.91 (0.80)

**Table 2.** Rule Break and Intrusion Errors (standard errors are given in brackets).

	Frontal Lobe Patients Mean (S.D.)	Controls Mean (S.D.)
Rule Breaks	5.31 (0.44)	6.94 (0.05)
Intrusion Type I Errors	3.11 (0.72)	0.54 (0.19)
Intrusion Type II Errors	0.94 (0.37)	0.20 (0.05)

Table 3 shows the strategy formation results, with a significant impairment in the frontal lobe patients ( $F(2,66) = 6.47$ ,  $P<0.001$ ). Examples of strategy formation impairment are given in Figure 2, which shows the more haphazard pattern of searches in two individual patients, contrasted against the main strategy order. This type of pattern was found frequently in the patient group and varied in extremes of disorganisation.

**Table 3.** Strategy formation scores (a high score signifies a good strategy).

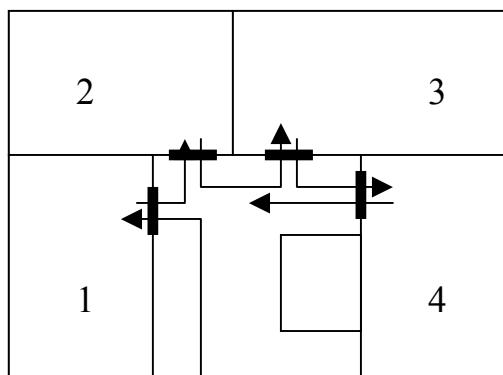
	Frontal Lobe Patients Mean (S.D.)	Controls Mean (S.D.)
Strategy Score	23.71 (1.65)	31.74 (0.91)

Table 4 shows the prospective memory results. For the activity based measures, there was no impairment in the frontal lobe group. For the time based test there was a highly significant difference in the unsigned measure ( $t(68) = 4.07$ ,  $P < 0.001$ ), and this reflected the patients being overall late in terms of reaching the front door on time ( $t(68)=3.77$ ,  $P < 0.001$ ). For the event related test, the patients selected significantly fewer of the fragile items ( $t(68)=2.23$ ,  $P<0.05$ ).

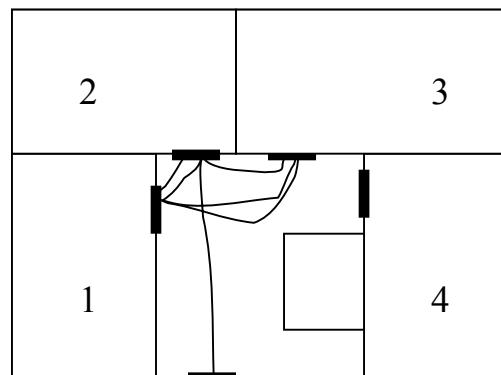
**Table 4.** Prospective Memory Scores (standard errors are given in brackets).

	Frontal Lobe Patients Mean (S.D.)	Controls Mean (S.D.)
Activity based – front door	0.69 (0.07)	0.54 (0.08)
Activity based – room two	73.01 (5.41)	81.08 (2.93)
Time based – unsigned (sec.)	76.18 (9.42)	31.72 (5.51)
Time based – signed (sec.)	62.27 (10.88)	14.30 (6.55)
Event based	3.19 (0.33)	4.10 (0.25)

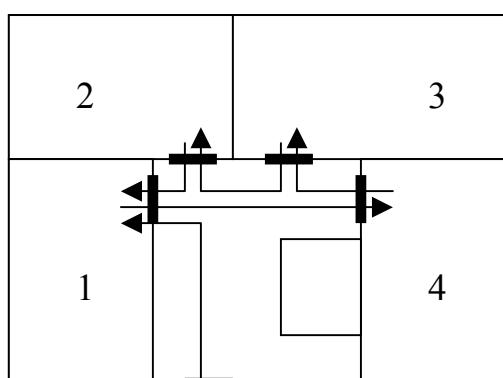
1234 strategy



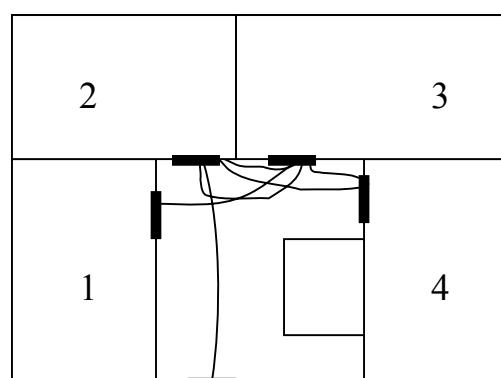
frontal patient 1



1432 strategy



frontal patient 2



**Figure 2.** The dominant path strategies on the bungalow task and examples of poor strategy two frontal lobe patients

#### 4. DISCUSSION

The Bungalow procedure was successful in providing an assessment procedure for the frontal lobe patients. All patients were able to follow the basic procedures and navigate around the bungalow, responding by selecting objects. Also, despite the multifaceted nature of the test, they were able to understand the rules, with part of the training procedure requiring the participant to explain back the procedures to the experiment, with the aid of the cue card. The patients also completed the task in the same amount of time as the controls, although they visited less rooms and showed less efficient strategies, increased rule breaks and impairments in prospective memory.

A significant increase in rule breaks is characteristic of frontal lobe damage (Goel and Grafman, 1995) and the current procedure shows how this can be systematically measured using a computerised procedure. In this case the rule breaks consisted of not following the instruction to collect a particular category of furniture first before moving on to the next one. Here it is clear that the instructions were well understood and the procedure relatively simple, as indicated by the near perfect scores for the controls. In contrast, the patients showed a clear deficit as a group. Additionally, they also had a tendency to interject their collection of a particular category by going back to items not collected for previous categories (Intrusion type I errors). This reflected the more chaotic organisational style of the patients in general, where searching the categories was not so clearly delineated. The other type of intrusion error (type II) was going back to collect previous category items at the end of the series of searches. This is, in a sense, an ameliorative strategy, since it is required to finish the overall task. However, despite being less efficient in collecting the times, they did not show an increase in this type of response.

The task also elicited impairments in strategy formation, in which the frontal patients moved around the different rooms in less organised fashion than the controls. Such strategy formation impairment has been observed previously on spatial search tasks such as the spatial working memory task (Owen et al., 1990; Miotto et al., 1996), and shows failure either to develop a strategy to apply it systematically. Inspection of individual participant data suggested that the problem lies with sustaining the strategy since, the initial search path showed patients were demonstrated successfully the model strategies. In the current case, the strategy relates to a 'real life scenario' since many everyday tasks require 'parsing' in this fashion, with appropriate efficient approaches to reduce the amount of effort involved. In this sense, the Bungalow task shows how it is possible to bridge the gap between laboratory based procedures and everyday behaviour.

Finally, various prospective memory tasks were built into the procedure. These are made more realistic than many laboratory tasks, in that the background task (collecting the furniture), simulates something akin to everyday activity, and the foreground task requires a form of memory familiar to everyday life (e.g. remembering to close doors or looking out for someone coming). Three types of prospective memory were explored and the results suggest a particular pattern of impairment. No deficit was seen with the activity related memory and this may relate to fact that when moving through a door there is a strong associative link between opening the door and remembering to close it, such that the required activity is heavily cued. For the time related activity, where the participant had to remember to arrive at the door at the correct time, the frontal lobe patients did show a deficit, being significantly late as a group. Here the appropriate activity has to be 'internally generated,' with continuous time monitoring and this deficit is fairly typical of reports of everyday behaviour of such patients. The intermediate result with the event related task, where the fragile furniture had to be labelled, with a smaller, but significant deficit may represent the fact that, although the furniture cues the response, this may be a less well established association than the one of opening and closing doors.

This study points the way towards developing more ecologically valid tests to planning an organisation that have potential to be used for routine clinical assessments, with advantages of simulation, and demonstrated test sensitivity. Future procedures can be more finely honed into clinical tests, perhaps shorting the length, and combining with tests of other types of functions. Further developments in this area should lead to a range of clinically validated tests for use in elucidating neuropsychological impairment.

## 5. CONCLUSIONS

In conclusion, a virtual reality has been used to test executive functioning in patients with focal frontal lesions. This procedures used are shown to be sensitive to impairment and elucidated a pattern of impairment in terms of rule breaks, strategy formation deficit and impairment in time based and event based prospective memory. The advantages of this approach from an experimental point of view have been discussed, with the clear finding that this experiment validated the use of this technology for testing executive function.

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# Developing virtual vending and automatic service machines for brain injury rehabilitation

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## ABSTRACT

Two different approaches for developing virtual environments (VE) for brain injury rehabilitation are described and discussed. The two VEs are built with the VR software World Up in the form of virtual vending and automatic service machines. The result from the first approach is a virtual cash dispenser that has been tested on five patients with brain injury. Improving the VE according to the test results was found to be quite hard, since it is implemented in a way that makes it difficult to update the code. In the second approach independent programming modules were identified and isolated. The modules were used to build a VE in the form of a train ticket machine. The second approach seems to provide a fast and understandable way of building virtual vending and automatic service machines for brain injury rehabilitation. There might also be the possibility to add a graphical user interface on top of the modules so that, for example, an occupational therapist with no programming experience could build an arbitrary virtual vending machine.

## 1. INTRODUCTION

Brain injury rehabilitation is a long and difficult process that includes training of so-called instrumental activities of daily living (IADL). IADL training involves activities like preparing meals, doing housework, using a cash dispenser etc. and it is often used by occupational therapists when helping people with brain injury to manage their daily lives. Among other things, daily life means encounters with different vending and automatic service machines. On a regular day an average person might use a cash dispenser, a train ticket machine, a coffee vending machine and a parking ticket machine. A person with brain injury might not be able to use any of these machines, which limits this person's ability to perform his or her daily activities. Therefore, IADL training with VEs in the form of vending and automatic service machines could constitute a complement to conventional brain injury rehabilitation techniques.

## 2. PROJECT DESCRIPTION

The Department of Rehabilitation, Lund University Hospital and the Division of Ergonomics at the Department of Design Sciences, Lund University are presently co-operating in a long-term project (Davies et al, 1999; Lindén et al, 2000). Each department brings its own unique areas of competence to the project: the Division of Ergonomics is specialised in human computer interaction and 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.

## 2.1 Overall Project Goals

The main goal of the project is to determine whether a VE tool can be a useful component for the rehabilitation of people with acquired brain injury and an effective tool in everyday life. More specifically the project aims to

- find the optimal interface between a VE and the user;
- 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

Among these three applications are a virtual cash dispenser and a virtual train ticket machine that were developed using two different approaches.

## 2.2 Aim

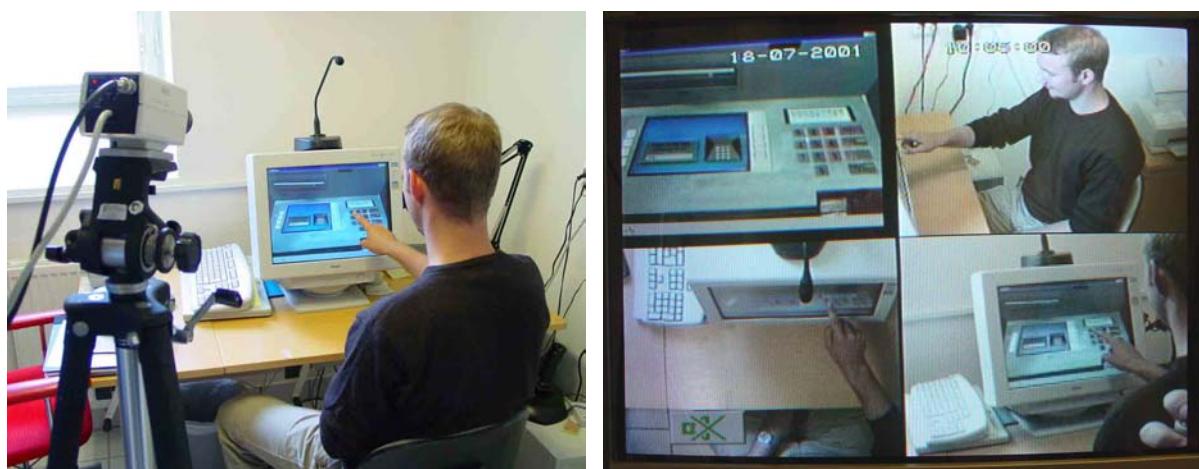
The aim of this paper is to describe the two approaches used for developing virtual vending and automatic service machines for brain injury rehabilitation. Also, the results of an evaluation made with the VE developed with the first approach is presented and discussed.

## 3. METHOD

Desktop VR was used for both the approaches mainly because of the cost and availability of such computer equipment in the hospital environment (Lindén et al, 2000). Also, Brown, Neale and Cobb (1999) have shown that people can learn well using desktop VR.

The vending machine of the first approach was developed with World Up, an object-oriented VR developer's kit in which VEs with complex behaviours can be created. The behaviours are implemented with BasicScript, which is a scripting language syntactically similar to Visual Basic. The main reason for choosing this VR software was that it works on ordinary personal computers, such as those found in a rehabilitation hospital. When the VE is complete it can be distributed to the hospital using the freely distributable World Up player.

Five voluntary brain injury patients participated in the evaluation of the virtual cash dispenser. The test group consisted of two men and three women and their age ranged from 28 to 58. Three of the test persons reported having problems using a cash dispenser and one test person had never used one. The task of the test was to make a withdrawal of 100 SEK five times in a row with the virtual cash dispenser. After the test an interview consisting of ten questions was made with the subject. Three video cameras were used to capture facial expressions, body language and hand movements of the subject when using the virtual cash dispenser. The monitor signal was converted into an analogue video signal and mixed with the video camera signals using a video quad splitter (Fig. 1). This was to provide an overall display on one screen to facilitate analysis. Also, a microphone was used to record comments from the subject.



**Figure 1.** Experimental set-up.

For the second approach the vision was to find a way to build virtual vending machines with World Up in a fast and understandable way. The idea was to identify and implement generic parts of vending and automatic service machines so that independent modules of code could be written. In this way an arbitrary machine can be put together in a fairly simple manner with World Up, which will hopefully save a lot of time and effort. To find the recurring features of vending and automatic service machines 18 different types of machines were studied. From this study it was concluded that most vending and automatic service machines of today can be described with the following six modules: slot, coins and notes, buttons, credit card, credit card reader and light emitting diodes. Most vending machines also have some sort of device for output of money, ticket and receipt. However this device is fairly uncomplicated and does not need to be described by a module.

#### 4. THE FIRST APPROACH: THE VIRTUAL CASH DISPENSER

The result of the first approach is a VE in shape of a cash dispenser (Wallergård et al, 2001) that has been tested on five brain injury patients (Fig. 2). It is an exact replica both in function and appearance of the cash dispenser of Sparbanken Finn, which is one of the bigger banks of the Lund region.



**Figure 2.** The first approach: the virtual cash dispenser.

The implementation of the virtual cash dispenser was made in three steps:

1. Made a simple 3D-model of the cash dispenser
2. Took photographs of the cash dispenser and put them on the 3D-model as textures, which is a common technique in VR modelling.
3. Programmed the behaviour of the virtual cash dispenser, i.e. the user dialogue, animation of objects, user interaction etc.

This first approach is characterized by code that is hard to reuse for similar applications since it is not divided into independent modules. Also, it is difficult to update the functionality of the virtual cash dispenser since it is hard to identify the different parts that need to be re-written. The virtual cash dispenser has been tested on five brain injury patients and the main results are as follows:

- the textures of the virtual cash dispenser were perceived as somewhat unclear
- one of the subjects had big problems with object interaction
- all the subjects had problems perceiving the computer screen of the virtual cash dispenser as a display

The test results indicated that the interface of the virtual cash dispenser was in need of improvements. However, altering the programming code was found to be not so easy. A lot of code had to be rearranged or rewritten.

## 5. THE SECOND APPROACH: THE VIRTUAL TRAIN TICKET MACHINE

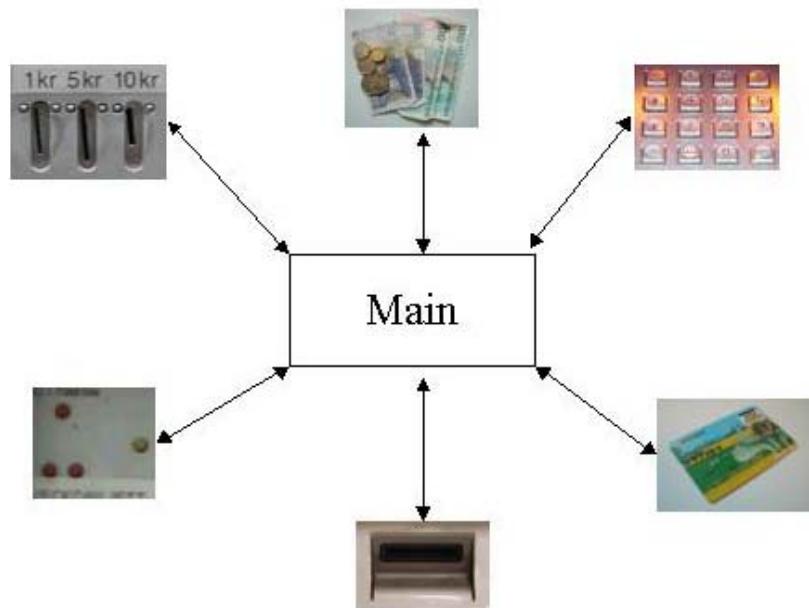
To overcome the problems of the first approach a second approach was tried. The idea was to identify and implement generic parts of vending and automatic service machines so that independent modules of programming code could be written. The results of the second approach so far is a collection of programming modules implemented in World Up and a virtual train ticket machine made with these modules (Fig. 3). The virtual train ticket machine is an exact replica both in function and appearance of the train ticket machine of Skånetrafiken, which is the public transport provider for the Skåne region in the south of Sweden.



**Figure 3.** The second approach: the virtual train ticket machine

Every module has a set of properties that describes the behaviours of the module. For example, the coin slot has a property called AcceptedCoins which is a list containing the coin types that are accepted by the machine.

The modules communicate with an object called Main, which is responsible for the overall decisions (Fig. 4). For example, it decides when it is time for the vending machine to change state.



**Figure 4.** The modules and the Main object

Once the modules were ready the virtual train ticket machine was implemented in three steps:

1. Made a simple 3D-model of the train ticket machine
2. Made textures of drawings found on the Skånetrafiken homepage and put them on the 3D model
3. Implemented the behaviour of the train ticket machine by connecting the six modules

The virtual train ticket machine has not yet been evaluated but tests with brain injury patients are currently being planned.

## 6. DISCUSSION

The second approach seems to provide a fast and understandable way of building virtual vending and automatic service machines. The virtual train ticket machine took considerably less time to build compared to the virtual cash dispenser. Another thing speaking in favour for the second approach is the results from the evaluation of the application made in the first approach, which indicate that it must be easy to update the programming code. Designing usable VEs is an iterative process made in several steps and therefore it must be possible to make changes without having to rewrite vast amounts of code. This can be done with the second approach whose independent modules facilitate changes in the code.

An idea for the future is to give persons without programming skills access to the second approach by giving it an easy-to-use drag-and-drop interface. That would make it possible for e.g. an occupational therapist to create virtual vending and automatic service machines for their patients to use in the rehabilitation process. Consider for example the following scenario:

Per, who is suffering from attention and memory problems as a result of a brain injury, has just begun his rehabilitation program. He frequently uses different food and coffee vending machines at work and therefore he wants to practice this activity. His occupational therapist starts the training by letting him practice on a real coffee vending machine. However, Per also wants to be able to practice this activity at home. Therefore, his occupational therapist uses a special program to construct a virtual coffee vending machine that looks and behaves exactly like a real one. The program has a graphical user interface that makes it easy to combine different pre-defined programming modules. She puts textures in the shape of photographs on the 3D model with simple drag-and-drop operations. With the ready virtual coffee vending machine it is now possible for Per to practice at home, at his own pace, as many times as he wants.

Another field of application for a program like this could be industrial design. A design team could use it to try different designs on a vending and automatic service machine by altering both its appearance and functionality in different ways.

Although the VEs described in this paper seem to provide usable training environments for brain injury rehabilitation some issues need to be investigated further. For example, we would like to examine the role of textures for this type of VEs. Are there differences between photographic and computer generated textures when it comes to usability? How true to reality must a virtual vending machine be in order to provide a usable training environment?

The Virtual Cash Dispenser can be downloaded from [http://www.eat.lth.se/staff/mattias/virtual\\_cash\\_dispenser.html](http://www.eat.lth.se/staff/mattias/virtual_cash_dispenser.html).

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# ICDVRAT 2002

## Session V. Enhancing Mobility

Chair: Sue Cobb



# **Walking aids based on wearable/ubiquitous computing – aiming at pedestrian's intelligent transport systems**

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## **ABSTRACT**

As contemporary transport system including developing Intelligent Transport System (ITS) is vehicle centered, pedestrians especially elders and 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. P-ITS consists of various components including wearable computers for people in special needs and distributed computers to sense and control environments. This paper presents two example components, that is, Intelligent Cane, a wearable computer for the Blind, and a ubiquitous computing system to obtain and visualize traffic flow of Pedestrians.

## **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.

Sasaki et al (2000) proposed “Pedestrian's Intelligent Transport Systems (P-ITS)”, which gives safer and more convenient environments for pedestrians, especially the weak in the traffic system, with intelligent walk-aids (wearable computers) communicating with smart way (Ubiquitous Computing Environment).

P-ITS consists of various components including wearable computers for people in special needs and distributed computers to sense and control environments. This paper presents two example components, that is, Intelligent Cane, a wearable computer for the Blind, and ubiquitous computing system to obtain traffic flow of pedestrians.

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 presents Intelligent Cane introduces the concept of surrounding presumption (Sasaki et al 2000).

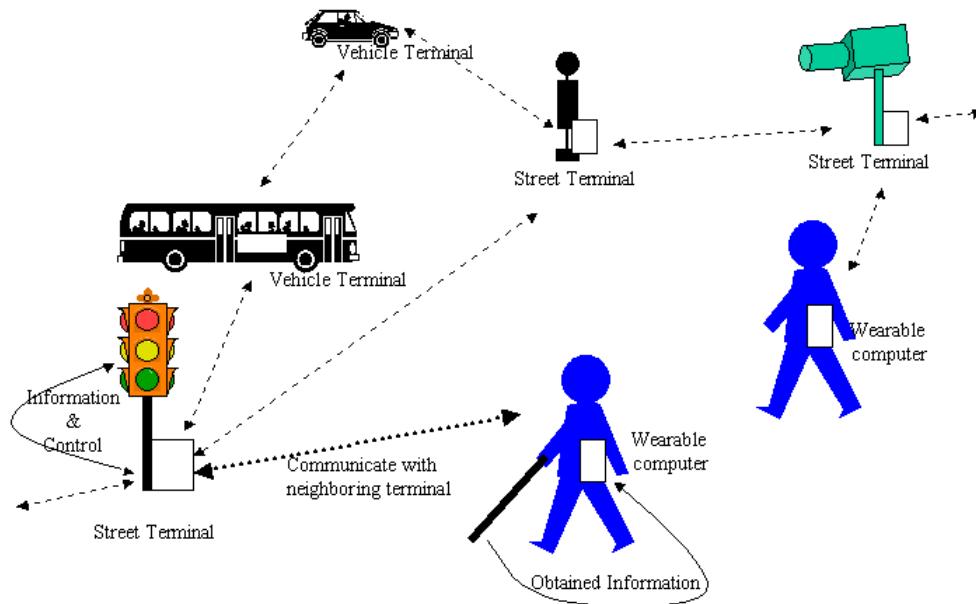
The person with walking difficulties wants to escape streams of people, as he/she cannot walk in a same speed as the stream goes. A visualization of traffic flow may help him/her to escape such streams. This paper proposes a ubiquitous computing system to sense and to visualize traffic flow of pedestrians.

## 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. For example, P-ITS may give substitutions of impaired senses of a certain person by translating information obtained by sensors on street terminals, P-ITS may realize pedestrian-centered traffic system with dynamic control of traffic infrastructure, such as traffic signals or moving walks as demonstrated by Nippon Road (2000), and P-ITS may produce mutual understandings and avoid unnecessary troubles among people by producing information as shown by Sasaki (2000).

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.



**Figure1.** The Infrastructure for Pedestrian's ITS

## 3. 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 such as ultrasonic range sensors converted into tone or volume of noise, may confuse its user with the flood of information. Sasaki (2000) proposed to compose all the walking aid into a cane and to give "surrounding presumption" function on the cane-shaped wearable

computer. This paper develops a prototype of such wearable computer named “Intelligent Cane”, and evaluates effectiveness of the situation presumption.

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. This paper concentrates to obtain the downward gaps.

Figure 2 shows the prototype system of the Intelligent Cane. The cane equips a slope sensor (INTERSENCE corp. INTERTRAX2) and an original active-stereo range sensor (Fig. 3) composed of 3 laser pointers (kantum electric corp. LD263-031) and a CCD Camera (WATEC corp. WAT-240R). The sensor system obtains the positions of three points on an obstacle or floor where the user heading to in 30 Hz. The mean square error of obtained position is 0.51cm and maximum error is 2cm inside target area. As the gap between roadways and sidewalks are no less than 5cm, the developed system holds enough accuracy for practical use.

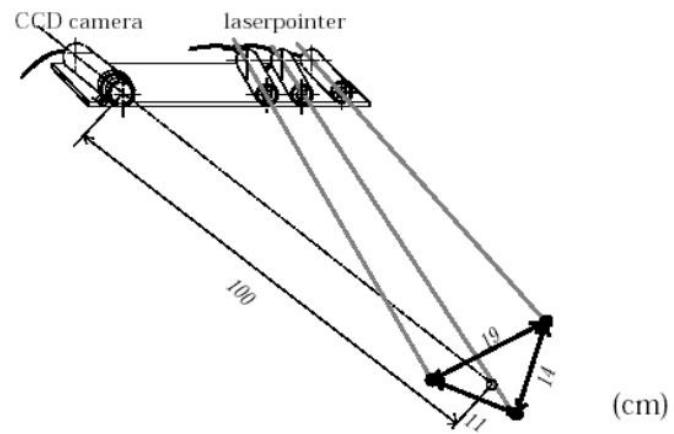
The cane presumes whether the user heading to normal floor, downward gap, downward stairs or standing obstacle using “floor-wall strategy” (Sasaki 2000) from obtained data. A Simulation cleared that maximum speed to let the cane to presume downstairs is 16.4km/h. As usual walking speed of human beings is less than 8km/h, the refresh rate of the cane is frequent enough for practical use.

The cane gives the presumed situation via voice and tactile signals. Three vibration devices embedded into grip of the cane as shown in Fig. 4 gives the tactile signals.

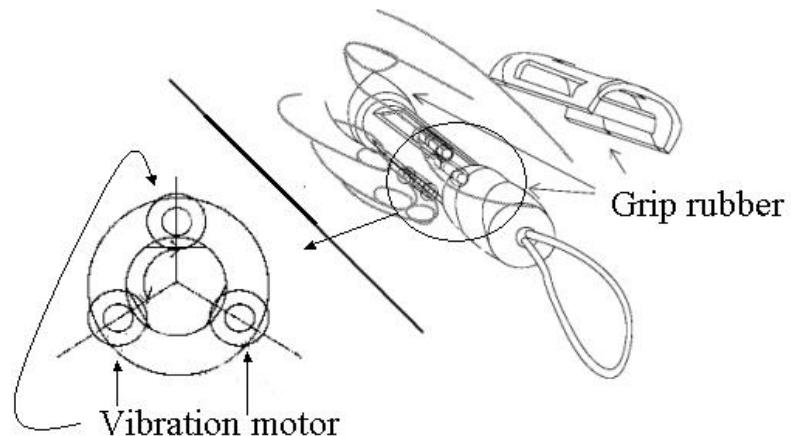
The output interface is examined by virtual walkthrough test. 15 subjects including two blinds asked to walk through virtual street shown in Fig. 5 using the Intelligent Cane. A subject swings the cane and an avatar walks along the virtual street depends on the swinging speed. The subject asked to stops when he/she notices any obstacles in front of him/her, and to report what he/she is heading to. Table 1 shows the experimental result. The subjects notice faster with tactile signals and understand better with voice signals. Additionally, the blind subjects claimed that they feel uneasy to use voice signals as it may disturb them to obtain other information, such as horns of cars. Thus, the experimental results indicate that the display system of the Intelligent Cane should have both voice and tactile channels.



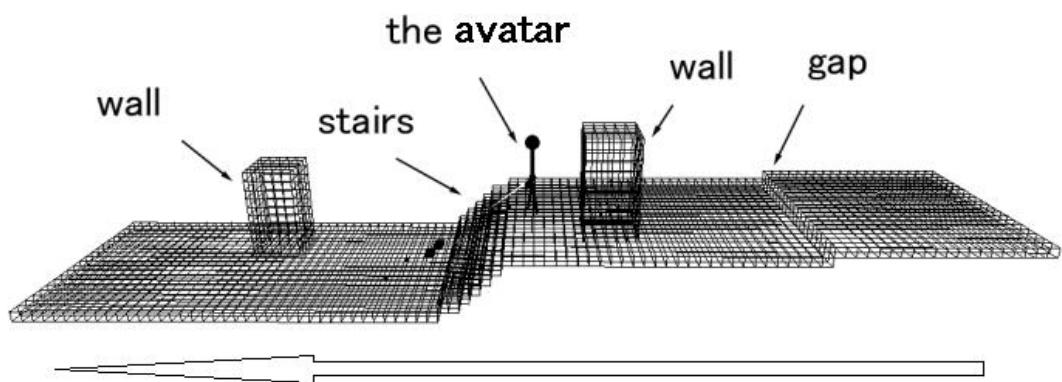
**Figure 2.** The prototype of Intelligent Cane.



**Figure 3.** The design of active-stereo range sensor



**Figure 4.** The design of tactile display



**Figure 5.** The virtual street for walk-through test

**Table 1.** The experimental result of walk-through test

	Average distance to obstacle when the avatar stops (cm)	Percentage of correct answers for obstacles' names (%)
Tactile signal	100	86
Voice signal	50	94

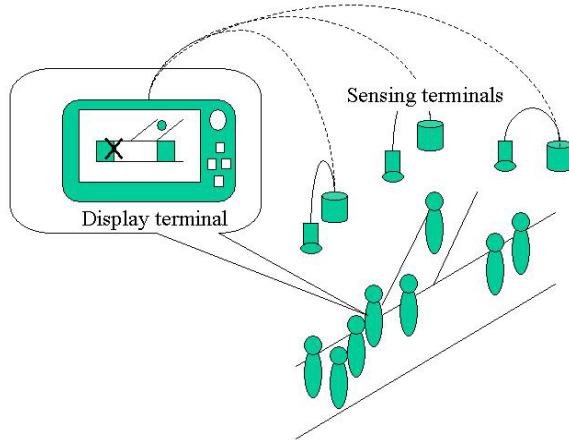
## 4. A UBIQUITOUS COMPUTING SYSTEM FOR THE PERSONS WITH WALKING DIFFICULTIES

P-ITS system is to produce pedestrian-friendly traffic environments under collaboration among ubiquitous computers. The authors developed an example prototype for feasibility study of the proposed concept. The person with walking difficulties wants to escape streams of people, as he/she cannot walk in a same speed as the stream goes. A visualization of traffic flow may help him/her to escape such streams. This paper developed a ubiquitous computing system to sense and to visualize streams of pedestrians.

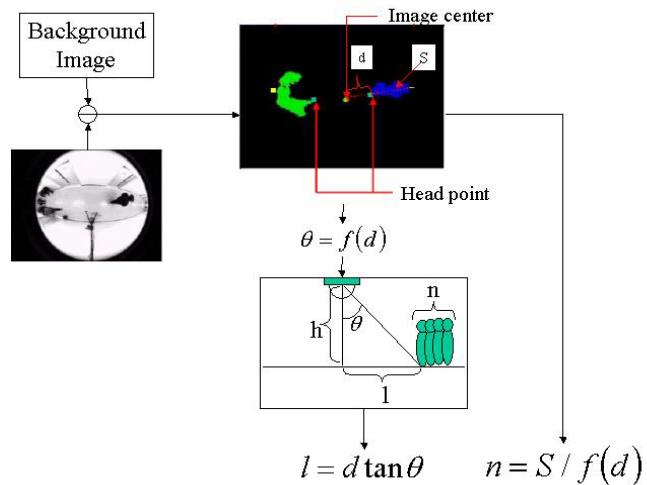
Figure 6 shows the conceptual design of the proposed system. The proposed system consists of street terminals to obtain size and direction of streams of pedestrians (sensor terminal), and information integration terminal to visualize obtained information on a street map (display terminal).

In order to obtain information of wide area, a sensor terminal equips a fish-eye-lens mounted camera. Figure 7 shows diagram to obtain target streams. A sensor terminal extracts person by differential imaging and estimates the head position of stream from a point on the contour of extracted region nearest to the image center. Fish-eye-lens lets the sensing terminal to work out via quite simple equation. The size of stream is worked out from the size of extracted region.

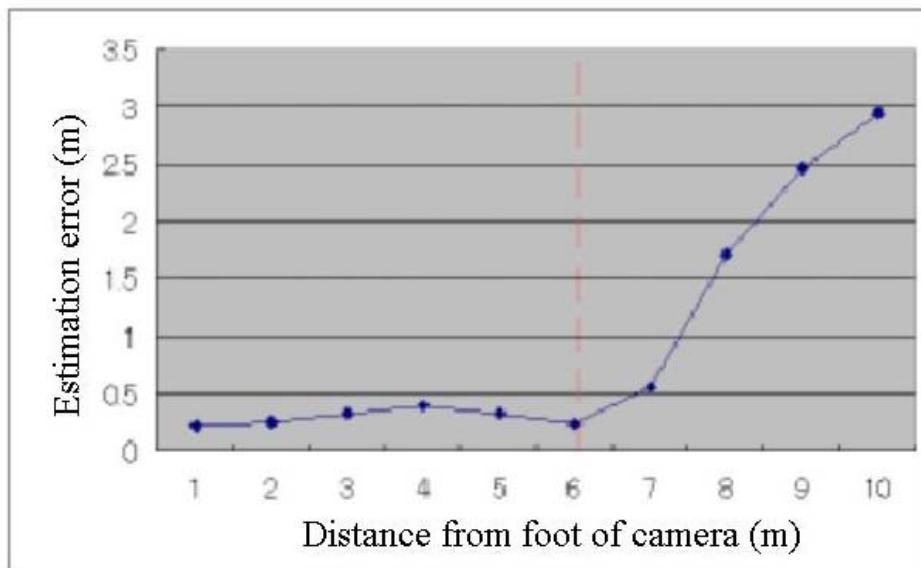
The prototype system is placed on a corridor of NAIST. Cameras are placed at height of 3m. In order to keep estimation error of distance less than 0.5m, the effective range of a street terminal comes to 6m according to Fig. 8. As the coverage of street terminals should have overlaps to hand over obtained regions, the authors placed street terminals every 8m. The evaluation result shows that the prototype system can estimate sizes and directions of streams properly when the street is not crowded. Although, further refinement of the prototype is required to make it applicable for crowded street, the result shows that the proposed system can obtain essential information to control P-ITS.



**Figure 6.** The conceptual design of traffic flow sensing system



**Figure 7.** Process flow to obtain head position ( $l$ ) and size ( $n$ ) of crowd



**Figure 8.** Estimation error along head position

## 5. 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 a wearable computer for the blind as one example of pedestrian's terminal. The wearable computer presumes surroundings to provide minimum safety information using range sensor and direction sensors. The prototyping and experiment using virtual environment clears that the proposed system can give proper information for the Blind via voice and tactile display.

This paper proposes a ubiquitous computing system to obtain traffic flow of pedestrians, which is essential information to control P-ITS system, using fish-eye-lens mounted camera. The prototype shows that the proposed system may obtain required information under limited conditions.

In order to demonstrate the feasibility of proposed framework, the further simulation based on real traffic flow obtained by the developed prototypes are essential. The authors are continuously developing prototypes of P-ITS and studying feasibility of the proposed system. The authors believe 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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# Research and development project for practical use of robotic travel aid for the visually impaired

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## ABSTRACT

Destined to the visually impaired, Robotic Travel Aid (RoTA) acts as an intelligent cart, guiding people across the streets. The 60 Kg, one-meter tall mobile robot is equipped with computer vision system, stereo camera sensor and voice interface. When moving, it is aware of its environment: It recognizes landmarks such as zebra crossing marks or traffic signals, stopping when the light is red, and “sees” cars or other pedestrians. In case of trouble, the robots communicates wirelessly with a Service Center, allowing to give extra information on the trajectory and adapt the navigational information system.

## 1. INTRODUCTION

Among 305,000 visually impaired people in Japan, about 170,000 people who lose their sight in elderly age cannot walk with either a long cane or guide dog. Most of them stay in their home and do not go outside by themselves. The guide helper of city hall and the volunteer group such as Japan Blind person Outdoor Support association helps them to go traveling. But when they want to go for walk or go shopping in daily life, they are not able to apply the guide helper system. In the large hospital or the home for the senior citizens the inpatient of visually impaired requires a nurse to move from his/her bed to somewhere else. To move when and where he/she wants, the device for mobility, orientation and navigation is developed (K. Melen, 1998). One of the solutions of the above requirements is the guide dog. But it requires training by the guide dog center. Its cost is estimated about \$40,000 in Japan. The user of the robot is required cares such as feeding, brushing and health care. The care cost is estimated \$3600 /year.

The intelligent wheelchair navigation system (SENARIO) is developed to guide the visually impaired in the indoor (N.Katevas, 1998). Also the personal adaptive mobility aid (PAM-ID) is developed for the same purpose (A.O'Neill, 1998). The aim of our project is to provide a mobile guide robot for the visually impaired when he/she goes for walk near his/her home or walk in the hospital or senior home. Twenty of RoTAs are produced to evaluate the robot in the real environment by the visually impaired of various level and to get the data for service and maintenance. RoTA is not for the visually impaired people who can walk with the long cane or the guide dog but for ones who cannot go outside without a helper.

## 2. DESIGN POLICY

We made the plan of R & D project of RoTA for one who cannot use the long cane and the guide dog. Its design policy is as follows:

- 1) *Mobility support*: One who loses one's sight is difficult to stand straight. The robot should be enough weight to support one's posture.
- 2) *Sensing for the mobility*: To get the mobility information such as the boundary of the road or the obstacle location, the robot should have a stereo sensor in the outdoor or infrared sensor in the indoor.
- 3) *Sensing for the orientation and landmark*: To get the orientation information such as the longitudinal direction of the road and crossing, the computer vision system is required(S.Kotani, 1996). It is also useful to identify the landmark and the traffic signal.
- 4) *Sensing for the obstacle avoidance*: In the road environment the robot should detect the car and the motorcycle. For this purpose the shadow underneath the vehicle is detected as the sign pattern (H.Mori, 1994, S. Kotani,1996). Both in the outdoor and in the indoor the robot should detect the pedestrian. For this purpose the rhythm of the foot is detected as the sign pattern (H.Mori, 1994, S.Yasutomi, 1996).
- 5) *Safe navigation*: For the safe navigation, the robot should follow the safer route from the start to the goal and follow the traffic regulation. For this purpose the route map specialized for the robot is required.
- 6) *Teaching the route map*: The digital map made for the car navigation is not useful for the robot, because it dose not represent the sidewalk and the cross walk. The operator of the normal sight has to select the safer route and make the route map. It takes much work and time to measure the significant point by the instrument. To solve this problem, the route map should be made by manually moving the robot along the route to memorize the mobility, orientation and navigation information.
- 7) *Communication before start*: Before start one has to select the rout by assigning the start point and the goal to the robot, and may ask how much time it takes to reach the goal. To make communication the robot should have non-visual human interface other than the display and keyboard.
- 8) *Communication after start*: The auditory sense is the most important sense for the echolocation among the residual senses. The robot should give him/her the information about the mobility and the orientation by its motion. In addition the vibrator should use to give him/her the orientation
- 9) *Battery*: The visually impaired may walk less than two hours every day. The robot should move two hours by one charging. During the stop at the sub-goal the robot should be power saving mode.
- 10) *Friendly looks*: The passenger and the driver near the robot are expected to give way. Therefore the robot should have noticeable and friendly looks
- 11) *Service center*: The service center is required to feed RoTA with the route information and to check and repair its breakdown.

### 3. SYSTEM CONFIGULATION

Following the above design concepts RoTA is developed. It is a motored cart of 500mm in width, 950mm in height, 1000mm in depth and 60kg in weight and is able to moves 2 hours in the velocity of 2-4km/hour. It is equipped with a color vision system for road recognition, a stereovision system or infrared system for the obstruct detection, sonar systems and bumper sensors for collision avoidance, a rear handle for supporting the balance of walking. Vibrators are attached to the both side of the handle to inform the user which side the robot is going to turn. A speaker and four push buttons are used for the menu input; in addition a voice recognizer is for the start point and goal input. Figure 1 shows RoTA's system configuration. Figures 2 and 3 show the photo of the RoTA and its handle and push buttons.

In the case of the teaching a note pc with a head-mount display and joystick are equipped. At first the operator of well sight performs the rout map teaching of RoTA. In the teaching he moves RoTA on the sidewalk from the start point to the goal or sub-goals and teaches it a sign pattern along which it should moves and landmarks by which it verifies the rout. A part of the rout is called *path* when the part is specified by the same sign pattern and the same navigation mode. The route is represented by a chain of the paths that written by XML.

### 4. THE ROUTE

The route from the start point to the goal is represented by a chain of path or path and landmark. The path is represented a line segment of trace with sign patter. Even a curved part of the route is represented by a part of polygon.

#### 4.1 Sign pattern and Landmark

The longitudinal visual feature along which the path lies is called *Sign Pattern* (SP in abbreviation) in this paper. In the road environment, the elongated feature on the road such as the boundary, the lane mark or the tactile block is a sign pattern. In the corridor the narrow board fixed at the lower part of the wall is a sign pattern.

Landmarks are grouped in three types (1) used for the current location correction in the position, (2) used for matching the current location up to the route, (3) used for the decision of go-stop. The crossing mark is one of the first types of landmark. The advertisement remarkable in the color is one of the second types. The traffic signal or the door of elevator is one of the third types.

#### 4.2 Teaching

At first we were going to make the route data from the digital map of ZENRIN 1/1500, because it shows the road, sidewalk and crossing in detail. But the work failed because the map represents the road only in the image, not in the vector format. It is very difficult to identify the sidewalk and crossing in the image by the computer vision. Next we tried to make the route data by measuring the significant points by the instrument of the civil engineering. It took one hours to measure several points. Moreover the measurements in the road are very dangerous and disturb the traffic. In this project the operator of the right sight selects the significant points and the SPs and the landmarks, and the robot measures its location and the parameters for the computer vision with its built-in instruments. We find it useful because (1) the data of the teaching and the practice are made with the same instruments, (2) measuring by the robot takes less time than that by the engineering instruments, (3) the measuring by the robot disturbs less the traffic than that by the engineering instruments.

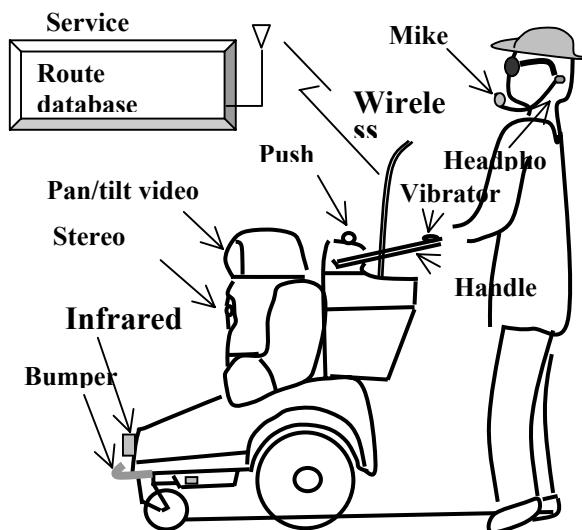


Figure 1. Configuration of RoTA.



Figure 2. RoTA.

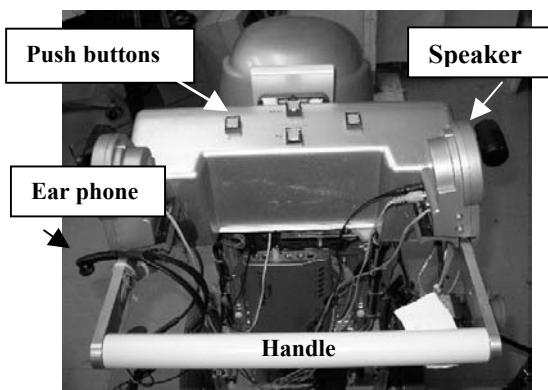


Figure 3. Handle and push buttons.

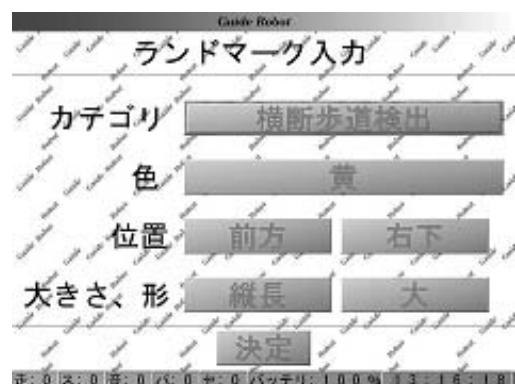
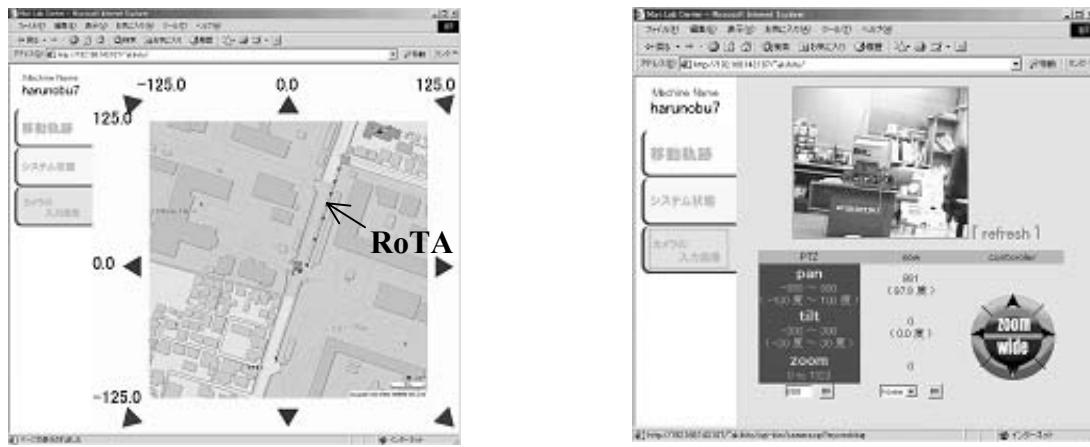


Figure 4. Display example in teaching.

The operator takes the head-mount display and moves the robot by manually control with the joystick, stops at the significant point and pushes the menu button. Fig.4 shows the image of the head-mount display. By pushing one of the menu buttons he selects the right icon or he inputs numerical data through the keyboard of PC. Fig.5 show display examples of the service center PC during the teaching. Fig 5 (a) and (b) show a RoTA trace on the map and a video image transmitted from RoTA during the teaching,



(a) A RoTA trace on the map. (b) A video image transmitted from RoTA.

Figure 5. Display examples of the service center PC during the teaching.

Line (3)-(6): Selecting the menu the operator specifies the navigation information that shows the locomotion pattern (GO-STRAIGHT, BACK, and SPIN-TURN) and the traffic regulation

Line (7)-(14): Selecting the menu the operator specifies the road information that shows the kind of road (INDOOR, OUTDOOR, SIDEWALK, ROAD-WITHOUT-SIDEWALK, CROSSING, ELEVATOR) the pavement (ASPHALT, BLOCK, LINO-LEUM, OTHERS) and the width of the path (line (10)-(13)).

Line (15)-(27): The operator fixes the start point of the path and the end point of the path. The data of both points (Line (16)-(20) and Line (21)-(25)) are given by the robot itself.

Line (28)-(56): The SP information is shown. Line (29)-(32) specifies the creation date (year, month, date) and the weather (FINE, CLOUDY, RAINY, SNOW). The former is given by the robot and the later is given by the operator. Selecting the menu, the operator specifies SP module (Line (35)) with its version (Line (36)). The operator directs the camera toward the SP by panning, tilting and zooming (Line (37)-(41)). The lateral distance of the SP from the robot is detected by its image processing system and is assigned in Line (42).

Line (43)-(55): The operator selects the SP in the video image by the menu. The selected point is stored in Line (44)-(48). Its search zone in the image is stored in Line (49)-(54).

## 5. R & D PROJECT FOR PRACTICAL USE OF RoTA

JSPS of Ministry of Education and NEDO of MITI financed 'R&D Project for Practical Use of RoTA for visually impaired.' The purpose of the project is to develop twenty of robots for test in the real environment by the visually impaired people. To make the robot practical it should be robust, power saving and low cost. To fit these requirements, the robot has to consist of as small number of elements as possible. HITACHI LABORATORY developed a small power saving image processing computer SuperIPcam, that consists of DSP (SH-4), vision chip (Super V chip), voice recognition and synthesizer middle ware and IO (Video in/out, Audio in/Out, LAN, RS232C). It operates in UNIX, 12W and 1.5W (in standby). Figs. 7 and 8 show the SuperIPcam configuration and that of Super V chip. Suzuki Motor Corporation Yokohama R&D Center developed a compact wheel built-in DC motor. Nihon Systemware Co. Ltd. developed Vision-based navigation system on SuperIPcam and Service center system on PC of Window. Fig.9 shows the software system configuration of RoTA and the service center. Fig.10 shows an illustration of the RoTA guide. Mori & Kotani Laboratory in University of Yamanashi developed SP & obstacle detection module, LM detection module and Locomotion controller. Saneyoshi Laboratory in Tokyo Institute Technology developed a stereo

camera system for such obstruct detection as pedestrian, bicycle, tree and garbage can. Nakaya-Seisakujyo Co. Ltd. developed the undercarriage. Professor Sanada designed the cover and handle of RoTA.

XML Code	Comment	Who	Means
<Date>20000719</Date>	(1) Creation date	Robot	
<PathName>TAKEDA SIDEWALK</PathName>	(2) Path name	Operator	Keyboard
<NaviInfo>	(3) Beginning of navigation		
<Navigation>GO-STRAIGHT</Navigation>	(4) Navigation command	Operator	Menu
<Regulation>ONE-WAY-STREET</Regulation>	(5) Regulation	Operator	Menu
</NaviInfo>	(6) End of navigation		
<RoadInfo>	(7) Beginning of Road infor.		
<RoadKind>OUTDOOR</RoadKind>	(8) Road kind	Operator	Menu
<Pave>ASPHALT</Pave>	(9) Pavement	Operator	Menu
<Width>	(10) Beginning of width infor.		
<Wide>500</Wide>	(11) Width of road in cm	Operator	Keyboard
<Boundary>300</Boundary>	(12) Distance from boundary	Operator	Keyboard
</Width>	(13) End of width info.		
</RoadInfo>	(14) End of road information		
<PointInfo>	(15) Beginning of points info.		
<Point1>	(16) Beginning of start point	Operator	Menu
<PointX>22</PointX>	(17) X coordinates in cm		
<PointY>60</PointY>	(18) Y coordinates in cm		
<PointDir>0</PointDir>	(19) Heading in degree		
</Point1>	(20) End of start point		
<Point2>	(21) Beginning of end point	Operator	Menu
<PointX>80</PointX>	(22) X coordinates in cm		
<PointY>60</PointY>	(23) Y coordinates in cm		
<PointDir>0</PointDir>	(24) Heading in degree		
</Point2>	(25) End of end point		
<Height>1</Height>	(26) Ordinal number of floor	Operator	Keyboard
</PointInfo>	(27) End of points information		
<SPInfo>	(28) Beginning of SP		
<CDate>	(29) Beginning of C.date	Robot	
<Date>20000719</Date>	(30) Year, month, date	Robot	
<Weather>FINE</Weather>	(31) Weather	Operator	Menu
</CDate>	(32) End of creation date		
<Category>SIDEWALK</Category>	(33) Category of SP	Operator	Menu
<Name> </Name>	(34) Name of SP	Operator	Menu
<Module>EDGE-DETECTION</Module>	(35) Name of module	Operator	Menu
<Version>1.0</Version>	(36) Version of module	Robot	
<Camera>	(37) Beginning of camera info	Operator	Cursor
<Pan>0</Pan>	(38) Pan in degree		
<Tilt>-10</Tilt>	(39) Tilt in degree		
<Zoom>1</Zoom>	(40) Zooming		
</Camera>	(41) End of camera info.		
<Distance>10</Distance>	(42) Lateral distance of SP	Operator	Menu
<Parameter>	(43) Beginning of SP parameters	Operator	Menu
<PointInView>	(44) Beginning of Point in view	Operator	Menu
<PntVId>BOTTOM-CENTER</PntVId>	(45) Point in the image		
<PntVX>10</PntVX>	(46) X of point in pixels		
<PntVY>10</PntVY>	(47) Y of point in pixels		
</PointInView>	(48) End of point in view		
<SearchArea>	(49) Beginning of Search area	Operator	Cursor
<SAreaLeft>0</SAreaLeft>	(50) Left of search area		
<SAreaRight>100</SAreaRight>	(51) Right of search area		
<SAreaTop>1</SAreaTop>	(52) Top of search area		
<SAreaBottom>0</SAreaBottom>	(53) Bottom of search area		
</SearchArea>	(54) End of search area		
</Parameter>	(55) End of parameters		
</SPInfo>	(56) End of SP		

**Figure 6.** An example of XML representation of the path.

## 6. RESULTS

RoTA was demonstrated in the Conference of Robotics Society of Japan at Tokyo University in Oct. 20<sup>th</sup> 2001. We have established Non Profitable Organization “RoTA Research and Spread Club” in 2002. Feb. In the open ceremony of the club, sixty complete blind elderly people tried RoTA in a small test course. Most of the complete blind people feel it helpful, because RoTA can guard them against the obstacle with its weight. On the other hand, weak-sighted people feel it useless, because it cannot go up and down stairs, cannot go into the vehicle. It takes only a half hour for the visually impaired to learn how to use the robot. Three of the complete blind people want to buy it when it is commercially available.

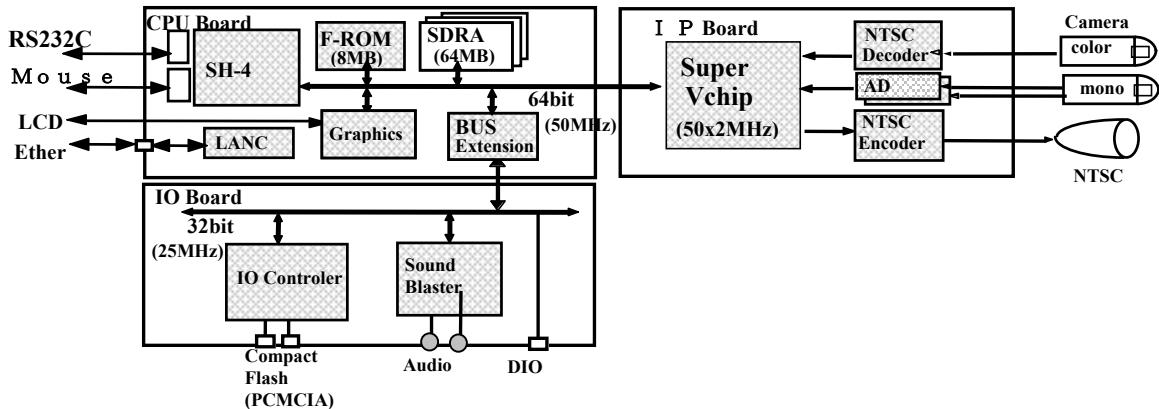


Figure 7. SuperIPcam configuration.

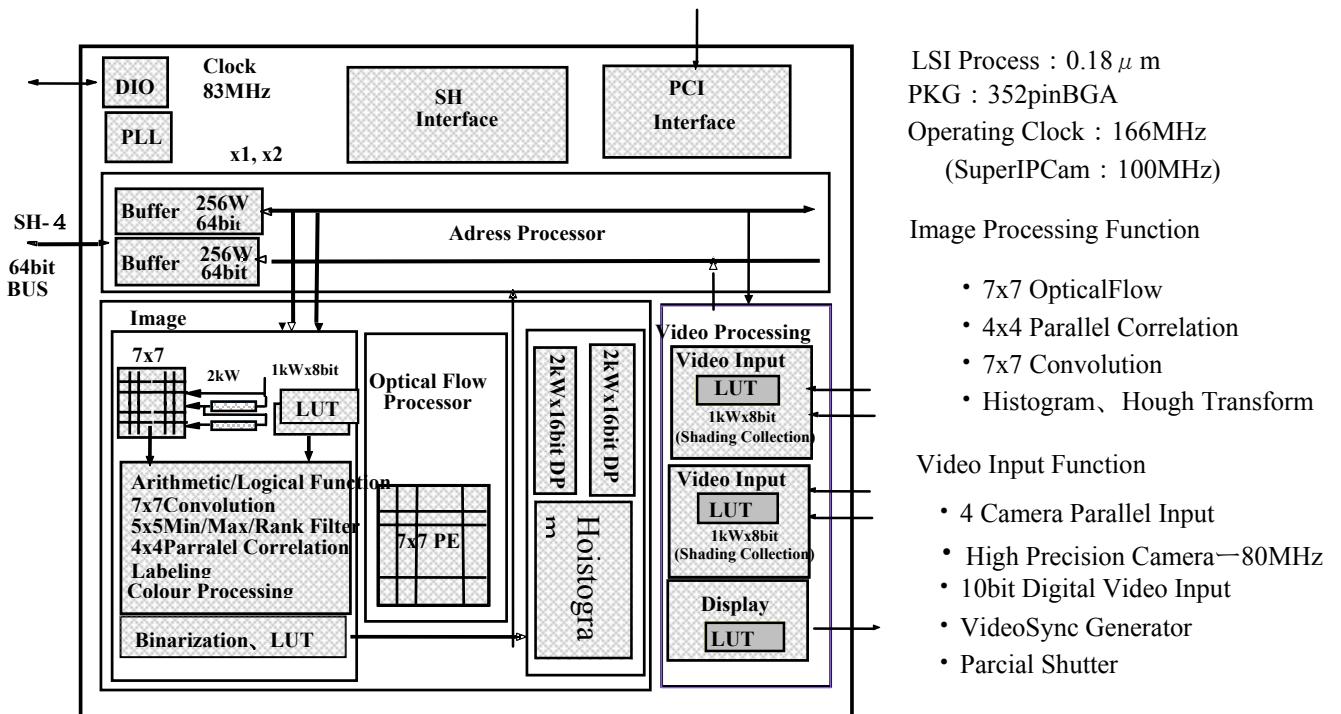


Figure 8. Super V chip configuration.

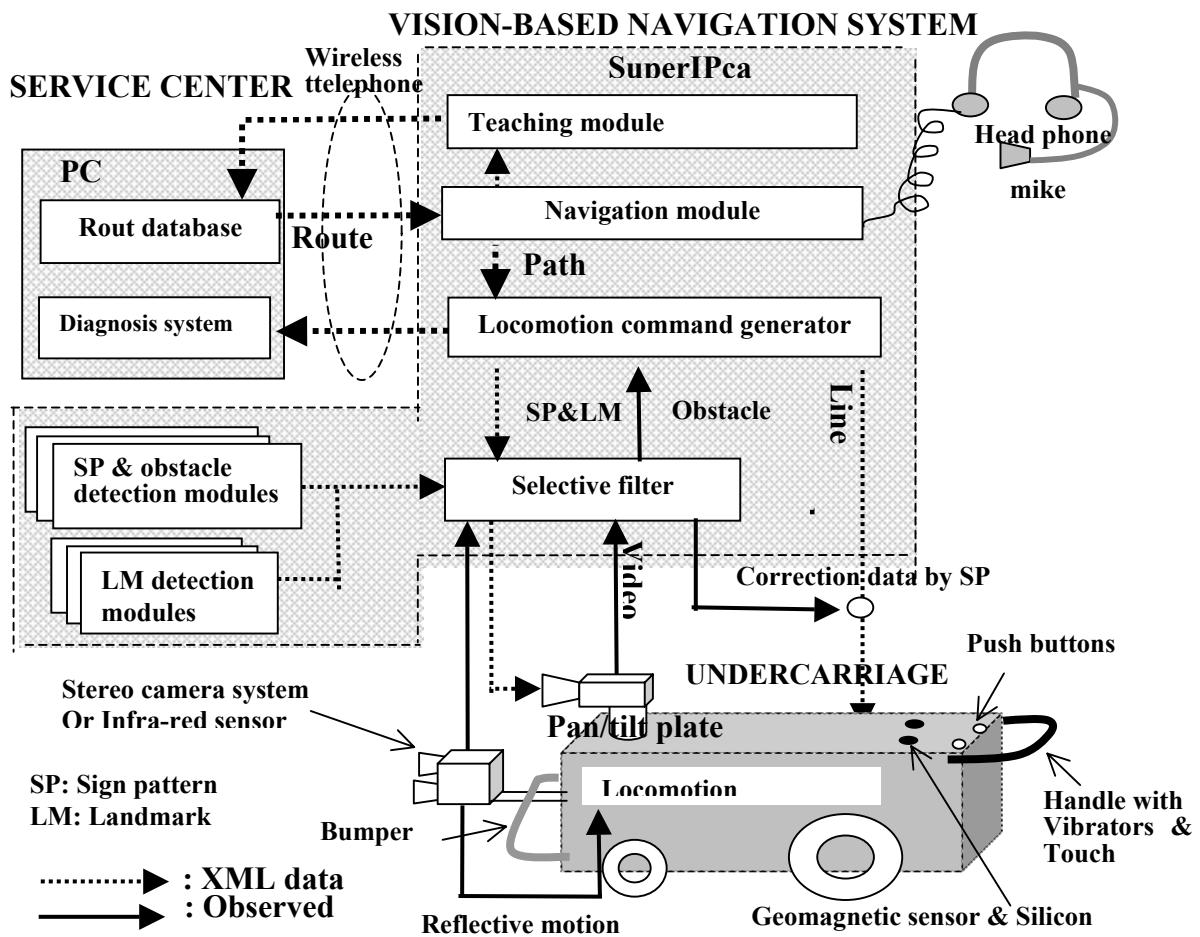


Figure 9. Software system configurations of RoTA and the service center.

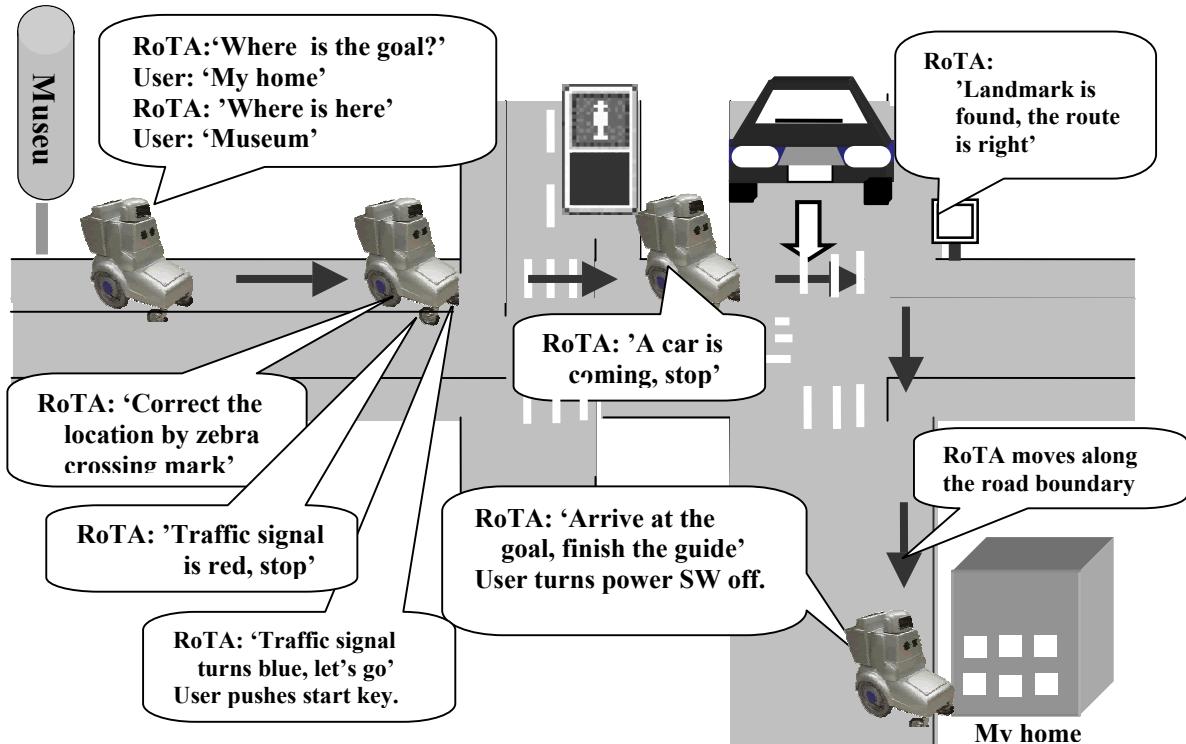


Figure 10. An illustration of the RoTA guide.

One is a man who lives in the senior home with his wife of right sight. The home is good for the robot locomotion, because the route is limited and its corridor is covered with the plain carpet, with little obstacle and of a little traffic.

The second is a woman who opens the clinic of acupuncture and moxibustion in the city of 100,000 populations. She wants to go for a walk with the robot. The road is wide and a little traffic. She walks in the neighborhood with a helper not in the sidewalk but in the road. The application of RoTA is not so difficult from the viewpoint of technology, but it has the problem of traffic regulation. In Japanese regulation, the visually impaired hast a long cane or a guide dog when he/she walks in the sidewalk or road.

The third is a woman who manages apartment houses with the guide dog about twenty years, but when she is over seventy years old, she feels difficulty to use the guide dog. She wants to use the robot for a walk in the asphalt-paved road, which runs up and down the hills. This case has the same problem as the second.

The field test of RoTA is to be applied in Hospital of University of Yamanashi this autumn. The inpatient of visually impaired requires a nurse to help his/her walk, so he/she cannot go anytime and anywhere. The robot is a good solution for these problems from the viewpoint of management and service.

## 7. CONCLUSION

We have developed twenty of Robotic Travel Aid (RoTA) in cooperation with three companies for the field. The aim of RoTA is to give a travel aid for the blind people who cannot walk without a helper. One can go to the friend and the drugstore in the neighborhood when and where he wants to go.

At first RoTA will be applied to the hospital or the home to help the blind inpatient or the blind citizen to walk in the indoor. Non Profitable Organization “RoTA Research and Spread Club” will do the field test in the hospital and the home to estimate the service cost of RoTA and will make the business model of RoTA. The club will take action of Japanese traffic regulation revision for the blind to use RoTA in the sidewalk. After the regulation revision the visually impaired can use RoTA by the rental.

The price of RoTA is depend on the number of production. It may be \$20,000 for 50 sets and \$10,000 for more than 100 sets.

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# Developments of a peripheral vision system using immersive virtual environment

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<sup>1-3</sup> <http://kotaro.aist-nara.ac.jp/index.html>, <sup>4,5</sup> <http://chihara.aist-nara.ac.jp/index.html>,  
<sup>6</sup> <http://www.shiga-med.ac.jp/~hqkikaku/SUMSGUIDE-e.html>

## ABSTRACT

Peripheral vision is one of the important vision that human eye has. To measure the peripheral vision is necessary because there is disease process that can affect the peripheral vision such glaucoma. However, the infant or the aged cannot have a peripheral test. They cannot utilize the conventional perimeter system. The authors proposed a newly perimeter system by utilizing Immersive display. This proposed system enables them to have a peripheral test easily.

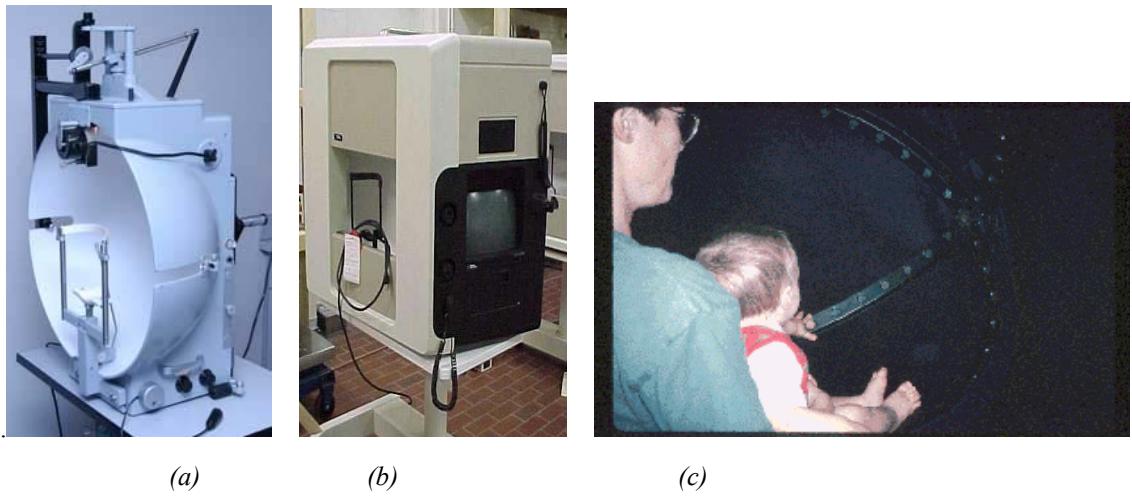
## 1. INTRODUCTION

Peripheral vision is one of the important visions that the human eye has. Peripheral vision is located in a retina that contains rod cells. The peripheral retina is sensitive to relatively low light and to movement. The primary job of peripheral vision is to make human aware of the location of objects in the visual space and to direct central vision toward a particular object. To measure the function of the peripheral vision is necessary, because the disease process exists that can affect vision field such as glaucoma. As a means of measuring the vision field, eye doctor utilizes a perimeter system, which is an instrument to measure the peripheral vision.

The perimeter systems have been developed (H.Goldman 1945; Zeiss; V Dobson et al 1998) and are divided into two types. One is the perimeter system based on kinetic perimetry such as Goldman Perimeter (Fig.1 (a)). The other is the perimeter system based on static perimetry (Fig.1 (b)). The kinetic perimetry based system is to see if a patient looks at the moving target that appeared in front of the patient with the patient looking toward a centered fixation point. The static perimetry based system is to see if a patient looks at the static target that projected on a screen.

However, these conventional perimeter systems cannot automatically judge whether the patient looks at the targets. When the patient saw the targets, the patient makes the eye specialist know what he/she saw by pushing a button. Thus, the diagnosis result depends on the patient. In addition, as the patient has been made to fix his/her chin on a board in a peripheral test, the patient is much tired. These problems have caused an infant or the aged not to have the peripheral test. In order to overcome the problem, a perimeter system for infant was developed (Fig.1 (c)). However, it is reported that this system couldn't give the doctors information enough to diagnose the disease of visual field. Therefore, the infant and the aged do not have any means to test the vision field. This is critical problem in the ophthalmology.

To overcome the problem, the authors proposed a newly perimeter system by utilizing an Immersive display. In this proposed system, the user does not need to fix his/her chins while doing the peripheral test. This proposed system is an instrument to judge automatically whether the user looks at the targets that appeared on the screen by processing the obtained images from a camera. This system enables the patient to have a test easily with the patient sit.



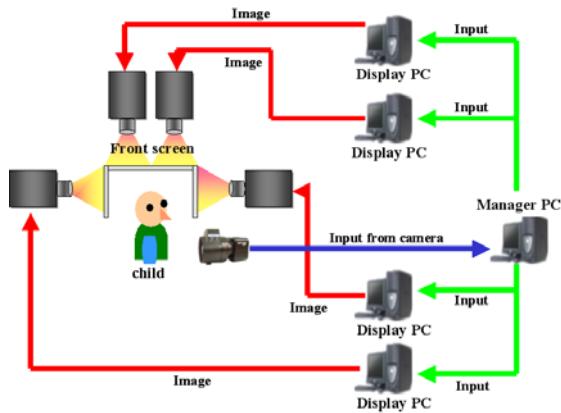
**Figure 1.** Perimeter systems (a): Goldman Perimeter, (b): Static Perimeter, (c): a perimeter for infant.

## 2. PROPOSED PERIMETER SYSTEM

### 2.1 Conceptual design

Fig.2 shows the block diagram of the proposed system. The proposed system consists of five computers, one camera and an immersive display. One computer captures user's face images from the camera that is put in front of the user. The others render the targets and the images of a centered fixation point constantly. The rendering images are projected on the four screens of the immersive display. The immersive display is CAVE-like system, which has four-faced screen: sides, face and bottom. The procedure in this system is as follows.

- 0 An operator determines the configuration concerning a perimeter test condition.
1. A server computer sends the configuration data to four client computers. The configuration data contains the colour of target and background, a timing to appear the target and vanish it, and so on.
2. Four client computers render the targets under the obtained configuration. One of client computers also renders the scene of the centred fixation point in a same time.
3. When clients finish rendering the targets and scene, they send a signal to the server.
4. When the server receives the signal from all clients, the server makes the operator know that the system was ready.
5. When the operator pushes the "start" button, the server calculates the positions and orders to render targets.
6. Finishing calculating them, the server sends a signal to clients.
7. One client received the signal renders the scene of fixation point. The others render nothing.
8. Some minutes later, the server sends the target's position to clients at intervals of the defined time. The server captures images from the camera and begins to detect the direction of user's eye in the same time.
9. When clients receive the data from the server, they render the targets in a fixed time.
10. When the fixed time passes, all clients send a signal to the server.
11. When the server receives the signal from all clients, the server stops capturing images and finishes detecting the eye direction. The server also sends the new target's position to clients.
12. Go to 9. The process from 9 to 11 runs for the fixed times.
13. When the process finishes for the fixed times, the peripheral test is finish and the test result is outputted.



**Figure 2.** Block diagram of proposed system.

## 2.2 Eyes detection

One of the features in the system is to judge whether the user reacts against the target. The proposed system runs the following process and judges that. First, in the proposed system, the server computer detects the eye's direction and the head movement of the users. Second, the sever computer compares the direction of user's eye with the position of a target and judge whether these directions are the same direction.

This explains about the eye detection procedure. The server computer ("Managed PC") captures user's face images from a CCD camera. The captured image is monochrome images. The camera is situated on the front poison of the user in order to shoot the face area (Fig.3).

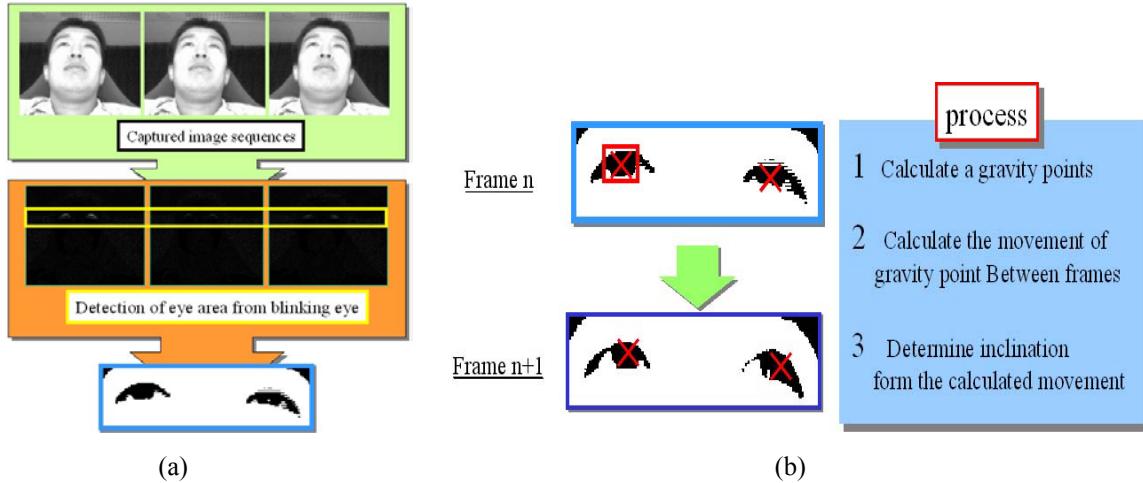
Managed PC detects a blinking eye of the user utilizing the inter-frame differential method from the obtained images. The eye area is defined the area covered with the area moved by blinking and the edge area of the user's face. Managed PC extracts the image in the eye area and makes the binary images from the extracted image by utilizing the threshold process (Fig.4 (a)).

Managed PC puts the label on the black parts concerning the pupil of the eye. Managed PC calculates gravity points in the black area from the binary image of eye area. It calculates the gravity points of black area every frame. Managed PC calculates the movement of the gravity points between the gravity point of a frame (n) and one of a frame (n+1). After calculating the movement, it calculates the inclination of user's eye in some frames by utilizing the movement. The direction of user's eye is calculated from the inclination (Fig.4 (b)). As the base point of the gravity point in first frame, Managed PC calculates the inclination of angle and determines the eye's direction from the inclination of angle.

Managed PC compares the eye direction with the target poison. If the target appeared in the eye direction, it judges that the user reacted correctly. If not so, Managed PC judges that the user did not react.



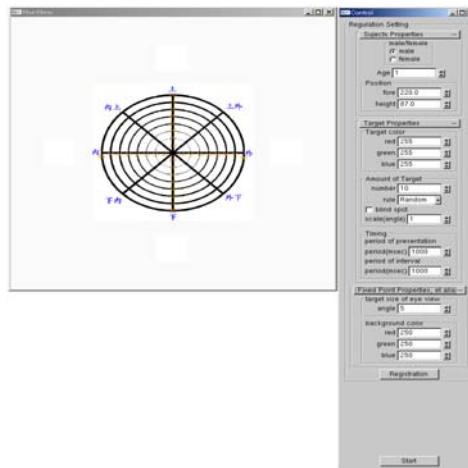
**Figure 3.** Camera position.



**Figure 4.** Eye detection process (a) extraction of eye area, (b) detection of eye detection.

### 2.3 Operation of the proposed perimeter system

When the eye specialist makes use of the proposed system and tries a peripheral test, they do the peripheral test by using Graphical User Interface (GUI) of this system (Fig.5). This GUI enables the eye specialist to set up the condition needed in the peripheral test. The setting items are as follows: the patient's sex and age, target's color, background color, interval till the target appears, vanishes and appears again and so on. The right area in this GUI determines the area that the targets appear by controlling the mouse. The left one determines the detail information such as the stated items. The reason that this GUI has the item to set the color is that the eye specialist tries the perimeter test, which is used the information of color difference.



**Figure 5.** GUI to control the proposed system.

## 3. EXPERIMENTS

### 3.1 Experimental purpose

As mentioned above, this research aims to develop the newly perimeter system, because the conventional perimeter system cannot measure the visual field of the infant or the aged. To overcome the problem, the authors propose the perimeter system, which can measure the visual field of the infant and does not make the infant feel tired. If the proposed concept has advantage in a peripheral test of the infant, the peripheral vision of the infant can be measured by the proposed system. Therefore, the authors developed the prototype perimeter system and experimented about the effectiveness of the prototype perimeter system. In addition, an eye specialist evaluates the prototype perimeter system.

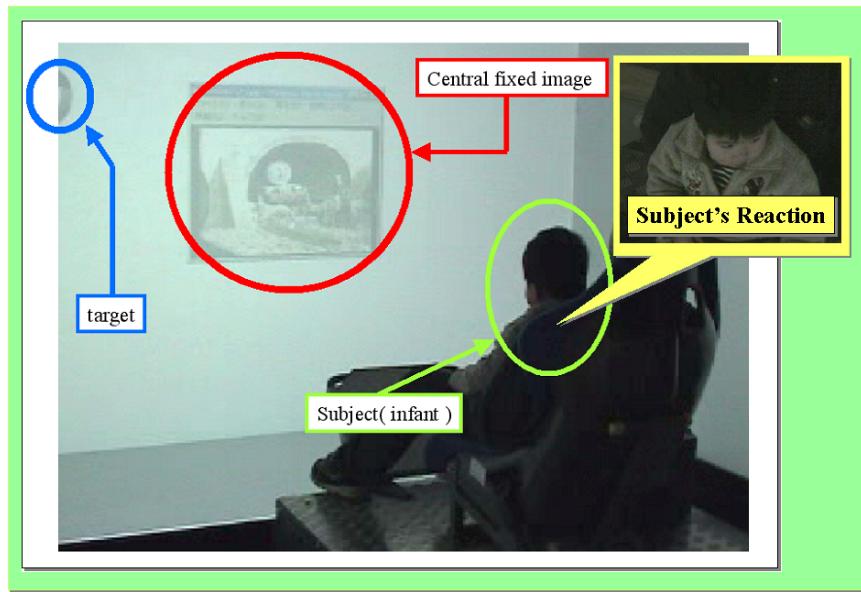
### 3.2 Prototyping

Table 1 shows the main spec of the prototype perimeter system and Fig.6 shows the snapshot of the proposed perimeter system.

**Table 1.** Main spec of the prototype perimeter system.

server computer	Dell PC OS: WinNT CPU:Pentium4 1.8GHz, Memory: 1.0GB, Graphics card: Geforce3 Ti500
client computer	Dell PC OS: Win2k CPU:Pentium4 1.8GHz, Memory: 512MB, Graphics card: Geforce3 Ti500
camera	CCD camera :WAT-100N (produced by watec co. ltd) Minimum object illuminance : 0.001 lux
network	Protocol: TCP/IP, 100Mbps connection
capture board	IP5005 image processing Board (produced by Hitachi)

The prototype utilizes the CCD camera that can use as the astronomical observation. During the peripheral test, it is so dark in the prototype that it's impossible to shoot the subject's face image by a normal CCD camera. As the capture board, the prototype uses the special board "IP5005", which is the instrument capable of image-process on the board, because the prototype needs to process the captured images in real time in order to detect the subject's eye direction.



**Figure 6.** Snapshot of the prototype perimeter system.

### 3.3 Experimental procedure

To have the subject look toward the center fixation point, the proposed perimeter system displays the images that the infant has interested in (Fig.6). After one minute, the proposed system displays the targets every 9 minutes. The targets are displayed on the positions instructed by the eye doctor (Fig.7).

The total number of displayed targets is 23. Target color is white and background color is black in order to enhance contrast between a target and background. The authors made the experiments under these conditions. The subjects are tested three times under the same condition by the proposed perimeter system. The subjects are two infants. One is a boy whose age is 2 years old. The other is a girl whose age is 4 years old.

#### 4. EXPERIMENTAL RESULTS AND DISCUSSION

Fig.7 shows the result of peripheral test against a boy. Circle area in Fig.7 shows the poison of displayed target. The circle area of white color means that the subject looked at the target in all peripheral tests and one of black color means that the subject did not look at the target. Gray color means that he could look at it in one or two times.

This experimental result states that the proposed perimeter system has a possibility that utilizing the proposed system tests the infant's peripheral vision. The reasons are two, which the proposed system has the possibility. One is to be able to make the result chart of a peripheral test from this experiment. It is difficult to make the chart by utilizing the conventional perimeter system. The other is the result that the subject wasn't tired of this perimeter till the test is finished. In this experiment, the subjects sit on the knee of their father. Thus, the condition may make the subject feel relieved and it seems that the subjects are absorbed in the situation of peripheral test. However, the proposed system measured the infant vision filed by using such a condition. Therefore, it seems that the proposed system is the effective system as to a peripheral test for infant.

Also, the eye doctor utilizes this prototype and is evaluated about it. The eye doctor reported that it would be possible to test a child's peripheral vision by the proposed system.

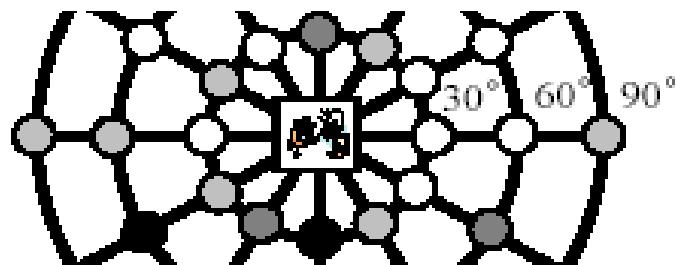


Figure 7. Peripheral test result of a subject.

#### 5. CONCLUSIONS

This paper proposed the newly perimeter system by utilizing an immersive display. The proposed system displayed the scene of the center fixation point and targets. The scene utilized the images where the subject is interested to have the subject look toward center fixation point. The proposed system could judge whether the subject notices the target by making use of image processing. The prototype system was experimented and the result proved the effectiveness of the prototype system.

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# ICDVRAT 2002

## Session VI. Communication and Interfacing to Virtual Environments

Chair: Roy Davies



# **Inclusive design of an interface for a hospital system for information, communication and entertainment**

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## **ABSTRACT**

This paper describes the features offered by a hospital portal system for information, communication and entertainment and the work underway to develop an interface to the portal such that all patients regardless of their age, disability, computer experience or native language can use it easily and effectively. The paper discusses the need for inclusive design of the interface to the portal and reports the results and evaluations accruing from the development of the interface to date.

## **1. INTRODUCTION**

Many hospital patients are isolated from telephone/electronic contact with their family, friends and workmates for the vast majority of their hospital stay, which is often a period of intense emotion. The role of the patient also requires the surrender of control over their life, which can be distressing, particularly as this loss of autonomy is often exacerbated by isolation. Relatives and friends also become disturbed by what they perceive as inadequate contact/information. The net result from a nursing point of view is added work on emotional support and as a messaging service.

Conventional mobile phones are banned from use within hospitals because their radiation poses a hazard to important electronic equipment including patient monitors, defibrillators and infusion pump controllers. However, recent advances in telecommunications hardware and software have made possible a safe solution to patients' communication problems, which is more convenient, less expensive and more reliable than existing systems. As a result of a collaboration of clinicians, hardware and software developers and providers a working prototype is now available for installation in hospitals. The system or portal consists of cordless (not mobile) high bandwidth audiovisual send/receive devices whose emissions fall well below the safety levels recommended by the Medical Devices Agency. The receivers communicate directly with a touch screen and telephone headset peripherally, and with a central server via landlines. Because the final link to the bedside need not be hardwired, disruption attendant upon installation can be minimal. Indeed landline installation in corridors and ducts can be coordinated with high-speed digital line installation being undertaken to provide a backbone for electronic patient records or administration projects.

## **2. THE HOSPITAL PORTAL**

The hospital portal prototype incorporates a range of information, communication and entertainment facilities that can be delivered directly to the bedside. For example the facilities provided include:

- Choice of terrestrial and cable/satellite TV channels (Figure 1).
- Near video-on-demand for classic films and 'box-office' movies.
- Selection of national, local, hospital and Internet based radio stations.
- Outgoing telephone services using a large button keypad, displayed on the screen (Figure 2).

- On-screen visual indication of incoming calls (audible / screen message) with controllable audible ringing tone.
- Full function voice mail service which is simple to operate and can be selected by the patient or by ward staff to eliminate interruptions caused by incoming calls, for example during ward rounds.
- On screen video games.
- E-mail.
- Hospital intranet access (Figure 3).
- Internet access to dedicated or ‘white list’ websites as specified by the hospital for example to health information sources such as disease-specific self-help groups.
- Nursecall facility with priority under the control of the patient.

The portal can also be adapted to serve clinical purposes, such as reminding patients to do their physiotherapy and providing copies of advice as already offered in hard copy in most units. Other novel patient-centred applications include meal ordering, pain monitoring, mobilisation and exercise prompts and motor retraining for stroke victims. It is also possible for nurses or consultants to use the portal to display at the bedside, via a secure link, patient records and imaging scans/X-rays.



**Figures 1-4.** A selection of facilities offered by the portal (television, telephone, internet, general menu interface).

### 3. INITIAL TRIALS AND CURRENT WORK

The interface to the portal has from the outset been designed with ease of use in mind. For example the main interface mechanism is a touch screen interface incorporating simple menus and large icons (Figure 4). Trials have already been undertaken in an orthopaedic ward at the Derbyshire Royal Infirmary in order to gauge initial patient feedback (Figures 5-8). Results so far have been exceedingly encouraging – “*it is wonderful really, especially for those patients that are bed-ridden. I have found it particularly nice to be able to watch TV from the bed and to use the telephone so easily*”.

However, whilst the interface is simple to use by the general population, it is currently inadequate with regard to use by some older patients. This is particularly true in relation to those patients who have auditory or visual disabilities, cognitive impairments, literacy problems, those who are inexperienced in the use of computers or those for whom English is not their first language. The focus of our work is therefore to research, develop and evaluate a 'design-for-all' interface to the hospital portal such that all members of the patient community may benefit from the facilities of, and stimulating environment created by, such a system.

## 4. THE NEED FOR INCLUSIVE DESIGN

Computer technology has the potential to enhance quality of life and independence for older people by providing access to information and services, including health care services (Czaja, 1997, 1998). However, age related declines in ability can be a barrier to accessing and using information and communication technologies if the interface has not been designed in a way that takes these changes in ability into account.

Our aim is to design the portal interface so that it can be accessed by everyone, regardless of age or ability. If a product is designed so that it is easy to use for older and less able people then it will also be easy to use for those who are younger and more able. This is the premise of inclusive design. Any interface that is not designed according to inclusive design principles, taking into account the needs and abilities of those who are older or less able, will exclude a proportion of the population that may be in most need of the information and facilities the system provides.

Work in this area is particularly important as older people form a significant client group numbering some 10.8 million in the UK (Office National Statistics, 2001a), with 1 person in 6 being aged 65 and over, a figure that is predicted to rise to 1 in 4 by 2031 (Age Concern, 1998) and whose proportion of the population will exceed that of the under 16s for the first time by 2016 (Office National Statistics, 2001b). Additionally almost half of the older population is aged at least 75, with even larger relative increases being experienced in people over 85 (Age Concern, 1998).



**Figures 5-8.** The hospital portal in use by patients at Derbyshire Royal Infirmary.

Studies into patient demographics show that older people also make up a high proportion of inpatients and that these figures are increasing annually (Department of Health, 2001). Additionally, as a person's age increases so does the average length of time they spend in hospital (Age Concern 2002). The General Household Survey (GHS) of 1998 reports that, over a three-month period, 27% of those aged 75 and over had attended a hospital casualty or outpatient department, compared with 16% of people of all ages. Furthermore, the average length of stay in hospital is longer for those aged 75 and over (12 nights for men and 13 nights for women) compared with all other ages (7 nights) (Office for National Statistics, 2000). According to the Office for National Statistics (2001b) in 1998-1999 nearly two fifths of hospital and community health service expenditure in England (around £10 billion) went towards people aged 65 and over. Expenditure per head on that age group being greater than for any other age group.

Disability also increases with age particularly in relation to issues such as visual and auditory impairment, cognitive loss, mobility decline etc. Around half of all disabled people in the UK are aged 65 and over. Only 4% of those with a disability are 16-24 in age, compared to 23% aged 65-74 and 26% aged 75 and over (Department of Health, 1998). It is estimated that some 5% of the population aged 65 and over and 20% of the population aged 80 and over suffer from dementia (Age Concern, 2002); between 30-60% of people aged over 65 have some level of hearing loss (RNID, 2002); and 70% of people with impaired vision are over 70 years old (Cawthra, 1999; Department of Health, 2001). Older people are more likely to experience multiple

impairment such as both failing sight and hearing, and chronic conditions such as osteoarthritis. Older people are also more likely to experience long-term illness. In the General Household Survey (GHS) of 1998, 59% of people aged 65-74 and 66% of those aged 75 and over reported having a longstanding illness, compared with 33% of people of all ages (Office for National Statistics, 2000). The GHS also reports that older people are likely to under-report chronic illness or disability.

## 5. DESIGN CONSIDERATIONS

Clearly, it is important that any information and communication technology (ICT) system that is intended for use by hospital patients should be designed to be accessible to all. Ageing can result in a combination of accessibility issues. Declines in sensory, perceptual, motor and cognitive abilities that occur with the normal aging process have implications for ease of interaction with ICTs and, hence, implications for interface design.

### 5.1 Age Related Changes in Ability

There are a number of sensory, perceptual, motor and cognitive effects of ageing that can affect performance of tasks, and which have implications for the design of the hospital portal. Many studies (see Morrow & Leirer, 1997 for an overview) have shown age-related declines in a range of abilities including:

- Visual and auditory perception
- Divided and focused attention
- Sustained attention
- Information processing in working memory
- Recall from semantic memory
- Speech processing
- Language production
- Movement control.

Performance is more likely to reflect these changes under complex task conditions (Morrow & Leirer, 1997).

Very little research has been carried out on what makes an interface easy for older adults to use. Some authors have described the various declines in abilities that occur with age and the implications of these for human-computer interface design (e.g. Morris, 1994; Czaja, 1996; Hawthorn, 1998a, 1998b, 2000). One study, by Ellis and Kurniawan (2000) involved participatory web site design with older users in order to make an existing web site more user-friendly for older users in terms of display format issues.

It is also important to remember that members of the older generation are likely to be new to computer technology, having retired without using computers or the Internet. Thus, they will not be familiar with many interface design characteristics more experienced users take for granted, that is they will not have built up the conceptual models of how these technologies work.

### 5.2 Disability

Some disabilities have an impact on a person's ability to access and use standard information and communication technologies. To use the computer people generally need to be able to:

- Use a mouse.
- Use a keyboard.
- See what is on the screen.

Not everyone is able to use a mouse or keyboard and not everyone can see what is displayed on a monitor screen. Those who are unable to do so may use some kind of alternative technology to access computers ("access technology" or "assistive technology"). Access technology is now sophisticated enough to allow a person who has just one functioning muscle group, e.g. someone who can at least blink, to use a computer. Computer interfaces can present barriers to users of alternative technologies, thereby excluding a significant proportion of the population. Interfaces should be designed so that the content and functionality of the system can be accessed, regardless of the technology used. Accessibility is not just a disability issue: people whose eyes and hands are occupied with other tasks, for example while driving, use alternative methods to access

ICT systems, e.g. speech output and voice input. It is important that the hospital portal is accessible to users with disabilities and is designed to be compatible with access technologies.

### 5.3 Native Language and Computer Naivety

Another factor that may impact on older users from ethnic minority groups is that of English not being their first language (Khoo, 2000). More generally, technological naivety may be another issue, although surveys show that 25% of people over fifty regularly use a computer and 81% of the group surveyed said they found it easy to use a computer with 59% using it to e-mail friends and family and 48% to surf the Internet (Age Concern, 2000). Convergence in the digital technologies is also making an impact in their use (Khoo, 2000; Wright, 2000).

We are therefore currently investigating with patient groups representative of all intended users of the system their requirements for a user-friendly interface to an information, communications and entertainment portal. These groups are being targeted towards the needs of older and disabled people and will specifically address the needs of those people with visual, aural, cognitive and motor impairments as well as those who are technologically naïve or have special learning needs or whose first language is not English.

Prototype interface solutions which embody these requirements and design guidelines (e.g. W3C, 2000; Disability Now, 1999; Trace.wise, Connecticut, NAIC, Abledata, all accessed 2002, McCrindle, 1998; Bright, 1997) are being implemented through incorporation of media types and technologies such as audio, video, graphics, sip and puff, icon and audicon design, speech translation systems, colour, metaphors etc. into the interface. Since February 2002, investigations have been taking place within the Low Vision Clinic of the Royal Berkshire Hospital and in Reading and Oxford Day Care Centres.

## 6. INITIAL INTERFACE APPEARANCE TESTING

### 6.1. Aim

The aim of this initial research was to set the parameters for the appearance of the hospital portal interface so that it will be easy to see and understand for all users in the target audience. That is, to determine:

- The appropriate icon and text size, icon polarity, and foreground/background colour combination that should be used in the default appearance of the interface.
- The alternative appearance options that should be offered to users.

### 6.2. Method

Software was written to present the participants with a number of test screens. Initial pilot tests were carried out with the clients of the Low Vision Clinic at the Royal Berkshire Hospital, in order to refine the software and test methodology.

The final test software comprised 5 screens:

- Initial welcome screen
- Icon size screen
- Icon design screen
- Text size screen
- Colour combination comparison screen

Throughout the testing the font style used for the text was Arial. The monitor screen used for the testing was a 17 inch flat screen. For each test session the illumination at and around the monitor screen was measured.

*6.2.1. Participants.* The participants for the interface appearance testing were clients of two Day Care Centre, one in Oxford and one in Reading. Clients of such centres have a physical or sensory disability and tend to be older people. Testing was carried out on location at the centres. In total, 94 people were tested (16 men and 78 women), age range 51-96 years (mean 81). This larger proportion of women is to be expected, given the age of the participants and the higher life expectancy of females. Participants were asked to describe any problems they had with their eyesight. The vast majority of participants were visually impaired in some way, ranging from age related sight loss with the need to sit close to the television, read large print books and wear bifocals all day, to more serious conditions such as cataract, glaucoma and macular degeneration. Fifty eight of the participants wore bifocal/varifocal lenses and wore these during the testing. The most commonly

reported eye condition was cataract, 14 who had existing cataract in one or both eyes, and 7 who had had the problem corrected by surgery. Five participants had glaucoma and 7 had macular degeneration. Two participants were registered blind. It is important to note that the majority of participants had multiple impairments with hearing loss and mobility difficulties in addition to poor eyesight. A few participants were cognitively impaired.

*6.2.2. Procedure.* The Software itself consisted of five screens and was pre-programmed in 800px by 600px screen resolution.

*Screen One - Initial Welcome Screen:* This screen was not only used to comfort the participants with its universal optician type display but was also used to determine the distance that the user needed to sit from the screen in order to be able to read the letters presented comfortable, for each participant this distance was measured. Four white letters (A,B,F,G) were presented in the centre of a black background, the text size being the largest of the alternative sizes used in the later text size screen (48 point, Arial).

*Screen Two : Icon Size Screen:* This was the first test screen. It presented four telephone Icons of different sizes (ranging from 3.28cm to 5.12 cm square – 93 to 146 pixels square) , black on a light yellow background, and the participants were asked to indicate the smallest icon that they could see clearly. The Icon used was that specified by BS 6034 / ISO 7001 “Public Information Symbols” (1990) for telephone, due to its universality and bold, uncomplicated shape (see Fig 9). The researcher mouse clicked on the participant’s chosen icon to record this in an underlying results file with minimal interface disruption.

*Screen Three - Icon Design Screen:* The Third screen was used to test polarity design of the icon. It presented two telephone icons, in the size previously chosen by the participant, one above the other. One icon was a dark foreground on a light background (positive polarity) and the other a light foreground on a dark background (negative polarity), as shown in Figure 10 Participants were asked to indicate the icon that appeared clearest to them, which was recorded as before. If necessary, it was possible to record a “no difference” result, in which case the dark on light icon was used as the default for the rest of the testing.

*Screen Four - Text Size Screen:* This screen was used to test the text size that participants found most comfortable to read. It presented the words “Phone call” in 4 different sizes: 18, 28, 38 and 48 point. The participants were asked to indicate the smallest text size that they could read clearly. This test brings up the issue of literacy – one participant stated that although they would indicate which word were clearer, they were unable to read them as they had never learnt to read. The participant’s choice was recorded as before.

*Screen Five – Colour Combination Comparison Screen:* This screen uses all the results collected from the previous screens and displays a telephone icon with accompanying text, “Phone call”, according to the participant’s earlier choices, in a number of different combinations of foreground and background colour.

In the pilot study participants were shown 10 individual screens, each presenting a particular text/ background colour combination as recommended by the RNIB (2002) for enhancing clarity. However, it was felt that for ease of use in the final system, the number of alternative appearance options offered to users should be kept to a minimum. Following the pilot study, the number of colour combinations used for the appearance testing were able to be reduced to 6:

<u>Text / icon</u>	<u>Background</u>
Black	White
White	Black
Black	Light yellow
Dark blue	Light yellow
Light yellow	Black
Light yellow	Dark blue

The experimental design used for testing the clearest colour combination was a paired comparisons. Each colour combination was presented with each other colour combination, so that, for each presentation, the participant saw once colour combination on the top half of the screen and the other on the bottom half. The order of the comparisons was randomised so that each participant experienced them in a different order. In addition, to compensate for possible differences in participants’ quality of vision in the top and bottom halves of the visual field, the colour combinations shown on the top and bottom halves of the screen were swapped

round for half of the participants. Participants were asked to name, 'top' or 'bottom', depending on which colour combination looked clearest to them, or if they about the same, a 'no difference' recording. In total, participants were presented with 15 pairs of colour combinations for comparison.

Using pre-programmed colour contrast presets, fifteen buttons are labelled with a number, each button representing a particular set of foreground and background contrasts, which when pressed are inserted into the two picture boxes (see Fig 9). To present the next pair of colour combinations the researcher hides the two picture boxes so that the user momentarily see a black screen, then randomly selects another button to display another pair of colour combinations for comparison.



**Figure 9. Paired Comparison Example.**

#### 6.2.3 Saving the Test File

All data resulting from the tests was saved electronically during the testing phase in an ASCII format for universality and to enable quantitative analysis to be undertaken. Any comments from the participants were also recorded during the testing process.

#### 6.3. Results

For the icon size test the majority of the participants (66%) were able to see the smallest icon clearly (93 x 93 pixels, or 3.28 x 3.28cm). With the icon design, 44% of participants felt that the light on dark design was the clearer, 34% felt the dark on light was clearer and 22% felt that there was no difference. For the text size the majority, 57%, were able to see the smallest size (18 point) clearly.

In the colour combination paired comparisons test, white foreground on a black background was most frequently selected as the clearest (237 times) and blue foreground on a light yellow background was least frequently selected as the clearest (83 times). There is little difference between the other 4 colour combinations (black on white 189 times, black on light yellow 135 times, light yellow on black 172 times, light yellow on blue 146 times). It is also important to note that for the majority of the comparisons (448) the participants stated that there was no difference between the pair of colour combinations presented. For the analysis each participant's choices were converted into frequencies for each colour combination (how often a particular colour combination was chosen as the clearest), which in turn were used to rank the colour combinations in order of preference (1=most preferred, 6=least preferred). This produced a rank order for each user. The rank totals for the colour combinations are shown in the table below:

Black on white	White on black	Black on yellow	Blue on Yellow	Yellow on black	Yellow on blue
238	182	298	357	240	281

As can be seen in the table above, white on black has the lowest rank total, which means that it was the overall preferred colour combination and blue on yellow, with the highest rank total, was the least preferred. Once again, there is little difference between the other colour combinations.

#### 6.4 Conclusions

While it may be sufficient to design the hospital portal interface using the smallest sized icon, as tested above, and a text size of 18 point, it is important to remember that 34% required a larger icon and 43% needed a larger text size. Few users (only the 2 that were registered blind) were unable to usefully see the largest icon and largest text size, in that they were unable to make out what these screens said. It is therefore concluded that the hospital portal interface can use the smallest icon and smallest text size tested in

this project in order to cater for the majority of older users, but should offer the larger sizes as options to users who are unable to see the default settings clearly. User with more serious visual impairments will need to use screen magnification or speech output.

There is little difference between the positive and negative polarity icon designs. The interface could have either design as the default and offer the other an alternative option.

In terms of the interface foreground and background colour combination, the important finding is that on the majority of occasions the participants stated that there was no difference between the two colour combinations presented. Although white on black was most frequently selected as the clearest colour combination and was ranked as the overall clearest, the difference between this colour combination and the remaining 4 is not great enough to justify sole use of white on black for the interface. Usability testing of the hospital portal prototype should include these alternative foreground / background colour combinations, but it may well be found that user orientation and navigation when using the system benefits from colour coding. In this case the default interface colour scheme may need to contain a number of different foreground colours, consistent throughout the system, that contrast well with the background, offering the foreground / background colour combinations tested here as alternative options.

## 7. CURRENT INTERFACE APPEARANCE TESTING

Whilst visual acuity tests are continuing as opportunities arise, we are mindful of the need to cater for other disabilities and patient requirements. We are therefore also conducting a series of other investigations and activities. For example in order to accommodate users who have problems understanding written language, either due to their educational background or specific learning difficulties e.g. dyslexia, and those whose first language is not English it is vital that the icons used in the hospital portal interface are meaningful. Work is thus underway in this area to identify a portal icon set. Work is also underway to develop more effective sip and puff interfaces, to add audicons to the portal and to visualise how people with different visual impairments perceive the same environment. Further details of any of these projects can be obtained from the authors. Focus groups are also being instigated with a number of elderly and disabled users in order to discuss our findings so far and to ascertain more precisely their requirements for the hospital portal and for computer based systems in general.

## 8. SUMMARY

In summary, this project is bringing together computer science, engineering and social science academics, with clinical and nursing practitioners and key charities, in order to address a wide spectrum of issues associated with care of the elderly and disabled in hospital. The resultant 'design-for-all' interface will enable the identified patient groups to benefit from the development of a hospital portal for information, communications and entertainment and a resultant better quality of stay in hospital with less feelings of isolation and social exclusion.

This programme of study is innovative both in terms of the facilities offered by the portal and in addressing inclusive design across such a wide range of disability groups. Although the target system for the developed interface is the hospital portal it is envisaged that the guidelines and tools developed will be applicable in the wider community across all applications that demand a computer user interface.

Experimental work carried out so far has gathered some useful information to help in the development of an interface for the hospital portal that will be easy to see for older users with age related sight loss, and, consequently, easy to see for all younger users with healthy vision. Further work needs to be done to investigate how the system should accommodate users with more severe visual impairments, e.g. by providing the facility for screen magnification or speech output. We are also now turning our attention to other impairment such as those of a cognitive, motor and auditory nature.

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# **Development of a computer controlled cognitive diagnostics and rehabilitation method for the use on the Internet**

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## **ABSTRACT**

In this paper we introduce a computer controlled method (HELp Neuropsychology = HELEN) which enables - as a difference to methods used internationally - not only the establishment of the diagnosis, but permits measurement of the effectiveness of the therapy. It allows

- To produce a database of the patients that contains not only their personal data but also the results of the tests, their drawings and audio recordings.
- It is an intensive therapeutic test which contains tutorial programs too.

## **1. INTRODUCTION: COGNITIVE COMPUTER AIDED THERAPY**

It is a computer controlled flexible procedure that enables clinical neuropsychological tests and therapeutic systems. The single tasks contain decision-making situations, for these the system provides material of assistance. The methods, how the patient solves the problems shows how he or she thinks about the question, in case of failure the system provides the possibility of a new trial. For these we had to elaborate such interactive procedures, which enable the solution along different concepts. This should not influence the test results, expressed in points, but should influence the way of rehabilitation. By this we enable the patients to control their own manifestations, and the way they deal with the problems. Thus this enables the use of the problem solutions encountered during the diagnostic phase and makes their transfer to the rehabilitation possible; it uses them in selecting the best strategy. The method uses syndrome-analysis, thus it is not only a mere collection of computerised tests, but has been built in such a form that it uses the solutions provided by the patient to choose the next task. At the same time it shows the efficiency numerically. By this it enables to develop diagnostic and therapeutic programs according to the individual needs and at the same time it supplies exact results and comparative data. This means that we investigate the cognitive and behaviour deficits in such a form that we activate the intact functions. The system contains tasks that relate to the perception, memory, attention, writing, reading, counting, etc. By this technique the patient controls the course by its own procedures, he or she is rehabilitated along his or her own activity, i.e. gets involved in the process and thus one can hope that the speed of his rehabilitation will increase. New aspect is that by using modern technical support, within the described system one can change the difficulty of the task by using colouring, changing the local or global intensity, adding noise.

The main menu of the HELEN program is constructed in such a way that the series of the tasks that was given in the beginning of the therapy can be changed any time depending on the patient's performance.

## **2. THE SPECIFICATION OF THE LOGICAL STRUCTURE OF THE HELEN SOFTWARE**

The software consists of three parts:

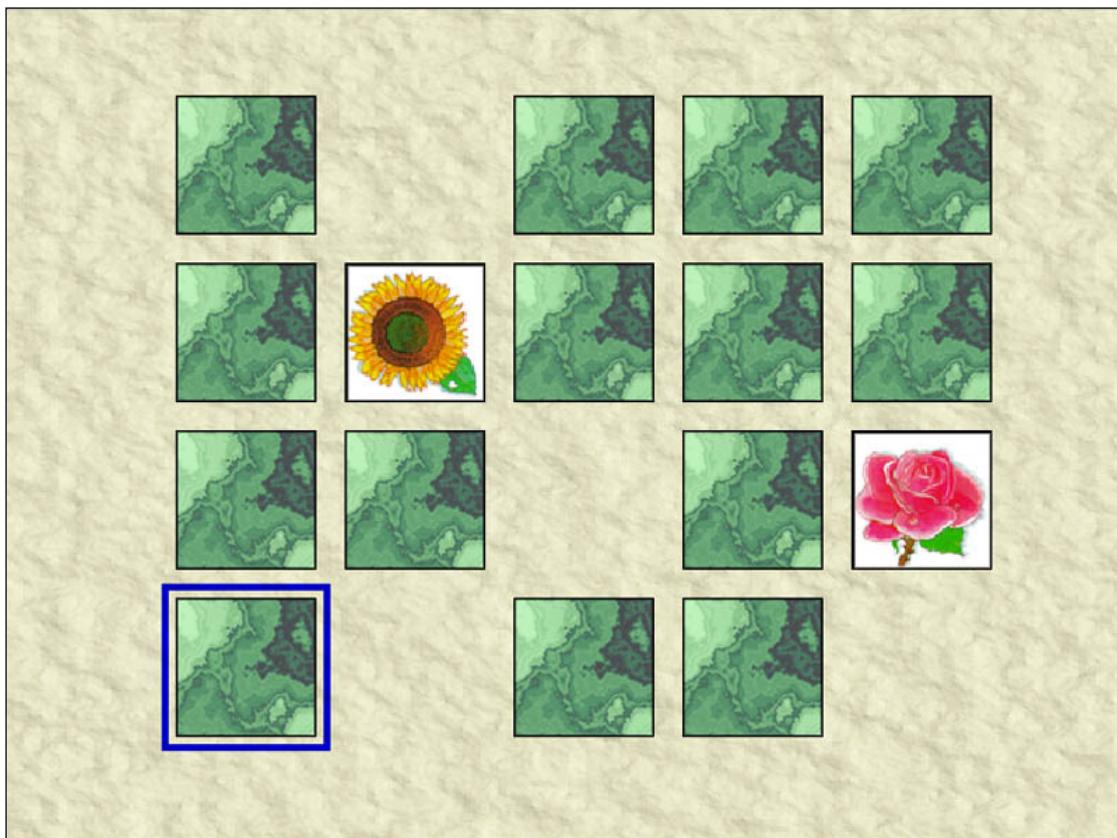
- A framework that manages the data of the neurophysiologists and the patients, and in which the series of tasks can be created.

Új orvos felvétele		
Vezetéknév:	Keresztnév:	
Páll	Attila	
Orvos azonosító:	00000001	
Telefon		
Vezetékes:	06/12-345678	
Mobil:		
Login név:		Jelszó:
Guszti		xxxx
Jelszó megegyezés:		
xxxx		
Cancel		OK

Új beteg felvétele		
Vezetéknév:	Keresztnév:	TAJ szám:
Szabó	Julianna	123456789
Ir.szám:	Város:	Utca, házsám:
8200	Veszprém	Egyetem u. 10.
Állampolgárság		
<input checked="" type="radio"/> Magyar <input type="radio"/> Külföldi		
Szül. dátum:	Szül. hely:	Anyja neve:
2002.06.13.	Kemecse	Fekete Julianna
Telefon		
Vezetékes:	06/12-345678	
Mobil:		
Cancel		ELŐTÖRTÉNET
OK		

**Figure 1.** Getting the data of the neuropsychologists and the patients.



**Figure 2.** Task Memory.

- The database that stores the data of the neuropsychologists and the patients, and the results of the tasks solved by the patients.
- The tasks

The following data are stored in the database of the software

Personal data:

- Name (maiden name as well)
- Name of mother
- Date of birth
- TAJ number (Hungarian social insurance number)
- Address
- Telephone number
- Name of next of kin
- Accessibility (Tel., e-mail)
- Left or right handed (this has to be known for the best strategy of some tasks)

Data obtained from tests:

- Results of the tests
- Strategy of solution
- Drawings prepared by the patient
- Audio recordings.
- Remarks of the neuropsychologist

The HELEN interactive therapeutic test and teaching software contains the following tasks:

Tasks available on Internet too	For medical examination only	For medical examination only
1. How many pictures do you see?	9. Recognition of faces	17. Story
2. How many black and white checked drawings do you see?	10. Stories similar to the Binet pictures	18. Ordering of sentences
3. How many cubes do you see?	11. Recognition of emotions	19. Clock
4. Where	12. Ordering according to form and colour	20. Situation practice
5. Labyrinth	13. Identify!	21. Blind map
6. Memory	14. Ordering of pictures	
7. Concealed pictures	15. Picture with noisy background	
8. Puzzle	16. Logical cards	

The tasks in the leftmost column can be downloaded from the internet too, so the neuropsychologist can give “homework”, to practice at home.

### 3. EXAMPLE TASKS IN DETAIL

#### 3.1 Memory

This game is similar to the traditional memory game, but the pictures are chosen thematically. Pictures from different topics are included in each game: fruits, plants, vehicles, clothes, etc. Maximum 4\*5 sized memory game can be played. The patient can get verbal help after time limit or after several unsuccessful attempts. The program saves the steps of the solution.

#### 3.2 Puzzle

At the beginning we can see the pieces of a picture dispersed and rotated at the border of the screen. On the border of the picture to be assembled we can see the outlines of the piece to be inserted. The picture is fit into a frame. The program saves:

- The order of the chosen pieces (It's important to know whether the patient is left or right handed, because he or she starts elsewhere)
- If the patient tries to put a piece to a wrong place
- If he or she gives up inserting the chosen piece and chooses a new one
- the given helps

### 3.3 Where

The patient sees 4-5 3D objects and 4-5 horizontal plans. The task is to put the objects to the right plans. The program gives help only after several unsuccessful attempts, maybe it rotates the object, the patient can take a look at the bottom of the object, so he can compare it with the horizontal plans. The program saves the attempts and the given helps.

### 3.4 How many cubes do you see?

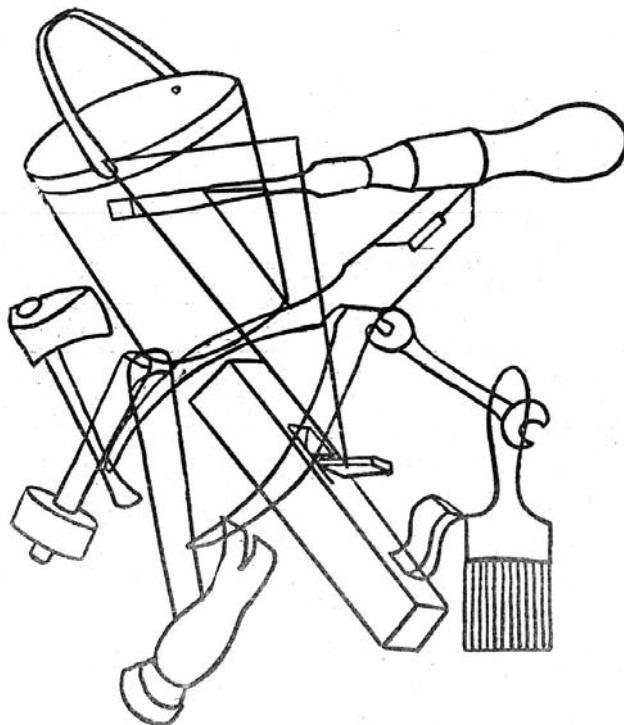
On the screen a 3D object can be seen, which is built of congruent cubes. The task is to tell the number of the cubes. If the patient doesn't know the answer, we can give a base plan where the patient can write in the number of the cubes in a given place. If he still doesn't know he can rotate the object. The program saves the attempts and the given helps.

### 3.5 How many pictures do you see?

On the screen 2D figures can be seen drawn onto each other. The task is to tell the number of the figures. The program can help with coloring the figures, or it chooses one and shades it. The program saves the attempts and the given helps.

### 3.6 Identify

Only one half of a number of 2D images of everyday objects can be seen, the task is to recognize the objects. The program can help with showing a similar object rotated. If the patient still doesn't know the answer, the program shows the original object rotated and in a different size. We save the number of the recognized objects. It's important to let the patient control which help he uses.



**Figure 3.** How many pictures do you see?

### 3.7 Ordering of pictures

We can see stories in 4, 6 or 8 pictures according to the difficulty level. The task is to put the pictures in an order. If the patient is ready with the ordering, he or she tells the story. If during the story telling the patient

recognizes that the order is wrong, he can put the pictures in another order. If he can't do it, the program gives sentences to the pictures. The program saves the attempts and the story telling.

### 3.8 Clock

The program tells the patient to draw on a circle the time he heard. The program can help with drawing the main lines of the watch. The program saves the attempts.

### 3.9 Story

We adapt known tales (only in foreign languages). On the screen we can turn over the pages just like in a book. The patient has to look at the tale, and has to tell the time he needs to tell the story. The program saves his story telling.

### 3.10 Labyrinth

The labyrinth program can be played with words or with numbers. This is asked at the beginning and then the size is asked (min 5\*5, max 20\*20). After that the labyrinth is drawn. The letters of a word or of a number from a mathematical expression are hidden as treasures. These treasures have to be brought out of the labyrinth in the shortest time. If all are brought out the program tells the time elapsed. Then we have to complete the word or the mathematical expression. The program saves the time needed to solve the program.

## 4. STEPS OF THE SOLUTIONS OF THE APPLIED RESEARCH

The group of interactive computer controlled rehabilitation programs makes it possible that we reveal the individual changes of the mental capacity of the patient, and by doing this get new information on the cognitive functioning of the patient or group of patients.

The information in the database reveals further data on the individual path followed by the patient, thus can provide information on the typical behaviour, how he or she recognises something, and gives us further insight in the sequencing of perceptions.

### 4.1 Expected results and further plans

We develop the HELEN software together with the organisation OPNI. After finishing the final version (expected for June 2004) it will be available for other institutions of Hungary as well. During the last two quarters of the project work we will already collect the results of the investigations. This will enable the testing of the progress of the rehabilitation of the patients. It is expected that these tests will provide us with data that can help to improve the method, and can cast light upon the possibilities when, under what circumstances and with whom the method can be used with the promise of success. Thus it might show also if there are personalities, persons, or groups of patients, or circumstances when the technique has no advantage or is even disadvantageous, e.g. in case of susceptibility to subordination. These observations and results of investigations will be useful also in other clinical departments.

## 5. SUMMARY

We have designed such an interactive multimedia test and tutorial software that helps the investigation and rehabilitation of stroke patients. The HELEN software enables the investigation of the cognitive deficits of stroke patients and their treatment in such a form that the patient becomes motivated to find his or her way of rehabilitation, to look for an out way in case of situations that threaten with failures, that he or she should choose an option from a number of possible solutions, and most important that he or she should direct the whole process. At the same time by using a computer it is important that the treatment of the problem should not get mechanic. We played attention to the fact that the patient should not get computer dependent, but the scale of the strategies how to solve a problem should become more diverse. Due to this fact the patients can go their own way naturally with the guidance of the neuropsychologue in their cognitive rehabilitation. This can improve their concern in their rehabilitation increasing their activity. On the other hand the method enables us to get an answer on the question what the most important criteria of the prospect of the cognitive rehabilitation are.

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# **Design of virtual environment input devices for people with moderate to severe learning difficulties – a user-centred approach**

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## **ABSTRACT**

This paper describes the continuation of research introduced in a previous paper: 'Access to Virtual Learning Environments for People with Learning Difficulties', presented by the Authors at ICDVRAT 2000 in Sardinia. The research stems from the development of virtual environments (VEs) for people with learning disabilities and findings of usability difficulties with the computer input devices. The first stage of the study, 'understand and specify the context of use', was achieved by conducting a Usability Context Analysis (UCA), which included an analysis of the user population, task and working environment review. The next stage, before proceeding to concept design, was to identify any existing computer input devices that satisfied the device requirements. No satisfactory match was found. Concept design generated many new concepts through the employment of concept generation methods, which were guided by the design specification. A concept selection matrix was then used to select the best concept against the device requirements. Evaluation of the chosen manufactured concept (VR1) followed. Objectives of this user-based assessment were to evaluate the usability of the new input system, to ascertain whether a User Centred Design methodology is a successful approach. The results of this study show that VR1 has greater usability than the more commonly used joystick and mouse for this user population.

## **1. INTRODUCTION**

Significant research has been conducted in the application of virtual environments (VEs) for people with learning difficulties. For example, the virtual city has been developed to teach independent living skills to this user population (Cobb et al, 1998). More recently, Rose et al have investigated the use of VEs in vocational training of people with learning difficulties (Rose et al, 2000). In this study, a preliminary evaluation of a virtual kitchen showed some positive transfer of training to a 'real world' kitchen test and provided clear justification for further development of this type of training. Research, which is rooted in developmental psychology theories, has indicated many benefits in the use of VEs for people with learning difficulties. For example, VEs: encourage active involvement in learning; avoid abstract thought; allow users to learn by making mistakes within a safe environment and provide access to previously inaccessible activities or places (Cromby et al, 1996).

Further research in this area has highlighted usability difficulties with the computer input devices, which are used to perform the VE navigation and interaction tasks. For example, from an evaluation of the aforementioned virtual city, it was found that individuals differed in the amount of support required to use the input devices; joystick for navigation and mouse for interaction (Cobb et al, 1998). It was also stated that navigation was found to be one of the most difficult tasks to do. The purpose of the research described in this paper was to examine the control of VE navigation and interaction tasks for young people with moderate to

severe learning difficulties, in order to provide guidelines for the selection or design of usable VE input devices for this user population.

## 2. BACKGROUND

Studies on the most appropriate methods of VE control for people with learning difficulties have concluded that the joystick and mouse are the most suitable navigation and interaction devices respectively (Hall, 1993; Brown et al, 1997). The aforementioned research by Cobb et al (1998) showed that people with learning difficulties experience usability difficulties with these input devices. However, this research did not provide detail of the specific problems that were observed. Hence, it was decided that a thorough evaluation of the joystick and mouse would be conducted to identify these difficulties and to clarify how research should progress. An evaluation of the joystick and mouse was carried out with 14 school pupils with moderate to severe learning difficulties (Lannen et al, 2000). This evaluation concluded that it is important to consider the physical and cognitive abilities of the user population, the tasks to be performed and the working environment, in order to select or develop usable VE input devices. This conclusion was supported by the following disciplines: human-computer interaction (HCI), user-centred design (UCD) and assistive technology (AT). Consequently, a multi-disciplinary design methodology, which was based on the key activities of the user-centred design (UCD) process (see British Standard ISO 13407), was carried out.

The first step of this methodology was 'understand and specify the context of use', which involved the analysis of the users, the tasks and the working environment, hence satisfying the conclusion of the input device evaluation and supporting disciplines. The methodology is described as multi-disciplinary as the following disciplines either provide the tools for a particular step or will be consulted during the methodology: user-centred design; psychology; ergonomics; product design; engineering and human-computer interaction. An outline of the multi-disciplinary design methodology is shown in table 1. This paper will outline the first 3 steps of the methodology, before focusing on steps 4 and 5: 'produce concept designs and prototypes' and 'carry out a user-based assessment'.

**Table 1.** *The multi-disciplinary design methodology.*

1. Understand and specify the context of use
- User, task and environment analysis (tool: usability context analysis (UCA))
2. Specify the user and organisational requirements
- Identify the design requirements (from UCA data, European Standards and relevant research)
- Identify device attributes (tool: product analysis)
- Design specification
3. Technology review
- Review computer interface technology (with reference to design specification)
4. Produce concept designs and prototypes
- Concept generation and selection (tools: product design methods)
- Embodiment design (tools: product design methods)
- Prototype manufacture
5. Carry out a user-based assessment
- Evaluation plan (evaluation method and usability metrics)
- Conduct usability evaluation
- Incorporate user-derived feedback into design process

## 3. UNDERSTAND AND SPECIFY CONTEXT FOR USE

### 3.1 Overview

The purpose of this step is to define the context of use of the VE input device(s), which involves the identification of the characteristics of the intended users, the tasks the users are to perform and the

environment in which the users are to use the system. The contextual data was gathered using the following tools:

- The context questionnaire from the Usability Context Analysis (UCA), available from NPL Usability Services (Thomas and Bevan, 1996)
- The Activity Analysis and Product Environment tools from the USERfit methodology (Poulson et al, 1996)

### 3.2 User analysis

21 pupils with learning difficulties, from the Shepherd School in Nottingham, were selected to form the VRD (Virtual Reality Device) user group. These pupils were selected by asking the teachers to recommend pupils whom: have the cognitive ability to understand the VEs; are not severely physically impaired and are interested in working with computers. The following characteristics of the user group were identified: skills and knowledge; cognitive ability; physical ability; perceptual ability; communication; behaviour and motivation. A selection of these characteristics is shown in table 2. Further details on the user data can be found in a previous paper by Lannen (Lannen et al, 2000).

**Table 2. Selection of user group characteristics.**

<ul style="list-style-type: none"><li>• Gender: 12 male, 9 female</li><li>• Age range: 7 – 19 (5 primary, 8 secondary and 8 from 16+ department)</li><li>• Skills &amp; knowledge: used VEs before – 6; good joystick control – 9; good mouse control – 10</li><li>• Cognitive ability: majority have severe learning difficulties; some pupils have moderate to severe learning difficulties</li><li>• Physical ability: the pupils have moderate physical difficulties, including the following: fine-motor planning – 19; gross-motor planning – 18; finger dexterity – 6; co-ordination – 14</li><li>• Perceptual difficulties: auditory processing – 14; spatial awareness – 17; directionality – 15</li><li>• Communication: use Makaton signing – 21; short sentences – 9</li><li>• Behaviour: distractible – 5; require encouragement – 6</li></ul>
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### 3.3 Task analysis

The objective of the task analysis was to develop a clear understanding of what the VE input device must do, so that a suitable device can be selected or designed that is fit for its' purpose. Three tools were utilised for this analysis: the UCA context questionnaire, a hierarchical task analysis and the USERfit Activity Analysis. The resulting data gathered is detailed in the context report (Lannen 2002).

### 3.4 Environmental analysis

The main tool used for the environment analysis was the UCA context questionnaire. This questionnaire required details on the organisational, technical and physical factors of the environment. The Product Environment tool from the USERfit methodology was used to compliment the UCA data. This tool considers the wider implications of how the product will be supported. The environment data collected is detailed in the context report (Lannen 2002).

## 4. SPECIFY THE USER AND ORGANISATIONAL REQUIREMENTS

The final objective of this step was to produce a product design specification, which lists all the requirements necessary to select or design a usable product. In order to reach the final objective, the following steps were conducted:

- Contextual requirements: requirement elicitation from contextual information (user, task and environment data)
- Requirement research: British Standards and HCI requirements
- Product analysis: specify how the requirements can be met through specific product attributes

#### 4.1 Contextual requirements

This step builds on the context of use data (user, task and environment data) and involves capturing the user-centred requirements for the VE input system. In the USERfit methodology, the term ‘functional implications’ is used instead of product requirements and it is stated that the functional implication is the bearing that each attribute (user, task or environment) may have on the design of the product (Poulson et al, 1996). Table 3 details a selection of the contextual requirements. All of the requirements were listed in the requirement specification (Lannen 2002).

**Table 3.** Selection of contextual requirements.

<i>User analysis data (feedback from questionnaire)</i>	<i>Requirement</i>
Hypotonic	Provides muscle support (arm/hand)
Motor-planning difficulties	Provides visual cues to function
Co-ordination difficulties	Slots/guides to assist user action
Ordering and sequencing difficulties	Minimal user input for task completion
Distractible	Motivational to use (motivates user)
<i>Task analysis data</i>	<i>Requirement</i>
Establish contact with navigation device	Ergonomic design of user interface
Use device to interact with VE objects	Buttons – easy to operate
Task duration: ~ 30 minutes	Durable
Mental demands: how to achieve navigation & interaction	Adaptable to user’s cognitive ability
<i>Environment analysis data</i>	<i>Requirement</i>
Interruptions: other pupils may distract user	Workstation helps focus attention on VE
Software required: VE platform	Compatible with VE platform

#### 4.2 Requirement research

It was important that the VE input device conformed to the relevant British Standards. Any of the requirements from the following standards that were not already covered by the requirement specification were added:

- ISO 9241-9:2000 – requirements for non-keyboard input devices
- ISO 9241-5:1999 – workstation layout and postural requirements
- ISO 9241-6: 2000 – guidance on the work environment

It was also important to ensure that the principles of interface design (from HCI literature) were covered by the requirement specification. These principles are: naturalness; consistency; relevance; supportiveness and flexibility. An examination of the requirement specification showed that these principles were already covered by the contextual and British Standard requirements.

#### 4.3 Product analysis

The product analysis is one of the USERfit methodology’s 9 summary tools. This tool is concerned with the functional aspects of the proposed product and involves describing how each design requirement can be achieved through specific product attributes. With reference to the requirements listed in Table 3, the requirement ‘provides visual cues to function’ could be met by the device attribute ‘form indicates function’. Employing this attribute would mean that the shape of the proposed product would indicate to the user how VE navigation and interaction is achieved. All of the device attributes were listed in the design specification (Lannen 2002). Table 4 details the device attributes that were specified to meet the design requirements in Table 3.

**Table 4.** Selection of device attributes.

<i>User analysis requirement</i>	<i>Device attribute</i>
Provides muscle support (arm/hand)	Ergonomic design of muscle support
Provides visual cues to function	Form indicates function (navigation and interaction)
Slots/guides to assist user action	Slots/guides to assist user action
Minimal user input for task completion	One user action = one VE function
Motivational to use (motivates user)	Accepts enthusiastic operation; modern style
<i>Task analysis requirement</i>	<i>Device attribute</i>
Ergonomic design of user interface	Ergonomic design (users 7 – 19, anthropometric data)
Buttons – easy to operate	Buttons – appropriate size and position
Durable	Robust mechanical/electronic design; durable materials
Adaptable to user's cognitive ability	Modifiable operation difficulty
<i>Environment analysis requirement</i>	<i>Device attribute</i>
Workstation helps focus attention on VE	Channels attentions to VE; built in carrels
Compatible with VE platform	Could mimic joystick and mouse input

## 5. TECHNOLOGY REVIEW

The aim of this review was to identify any existing computer input devices that met the device attributes in the design specification or could be adapted to meet these attributes. The following computer interface areas were reviewed, with reference to the design specification: assistive computer input devices; general computer input devices; virtual reality and gaming devices. As this technology review presented no input device to sufficiently satisfy the design specification or one that could be easily adapted to do so, it was necessary to progress to the concept and prototype design step of the multi-disciplinary design methodology.

## 6. CONCEPT AND PROTOTYPE DESIGN

### 6.1 Concept design

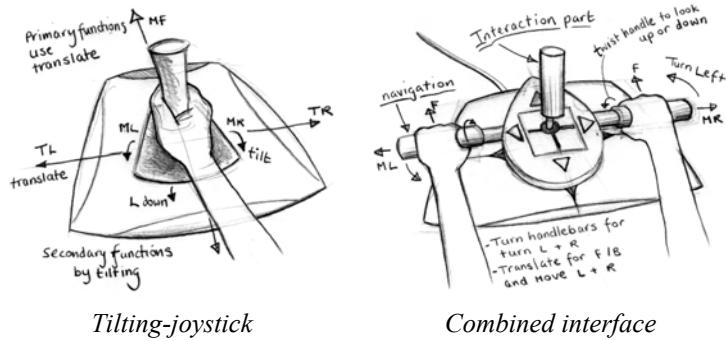
Concept design sets about producing a set of functional principles for how the product will work and a set of styling principles for the way it will look. A selection of the idea generation methods described by Baxter (1995), were utilised for concept generation, including lateral thinking (using analogies), the collective notebook and the theme board. The collective notebook was used to gather concept ideas from the usability team. The theme board is a collection of images of products that have the desired styling theme for the product under development and is used to inspire product styling.

### 6.2 Usability team review

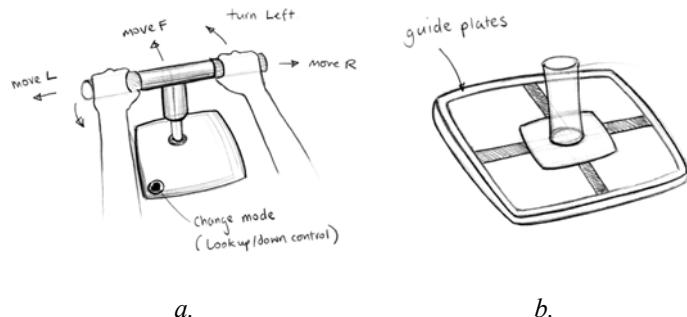
To assist in the selection of the best concept(s), the navigation and interaction concepts were reviewed by the available members of the usability team. The feedback gained from this review included the following: predicted difficulties with the concepts; good features of the concepts; new ideas or features to try and recommendations to discontinue researching particular concepts. The concepts that developed from this review are depicted in Figure 1.

### 6.3 Concept selection matrix

The concept selection matrix (Baxter, 1995) was used to rank the final concepts against the selection criteria. The selection criteria, in this case, were the device attributes from the design specification. The results of this method showed that the best navigation concept was either the 'combined interface' (Figure 1) or the '2-hands control' (Figure 2a) and the best interaction concept was the 'joystick' (Figure 2b).



**Figure 1.** Developed concepts from usability team review.



**Figure 2.** a – 2-hands control; b – joystick

One of the design specification attributes is ‘navigation and interaction functions in one device’. The benefits of this requirement are expected to be: *increased transparency* – as the user is not required to switch between devices; *increased focus on the VE* – as all functions will be centrally located on one device and compact design – *more integrated system*. Due to these benefits, and the results of the concept selection matrices, the decision was made to develop the ‘combined interface’ concept. Hence, this concept proceeded to the embodiment stage of concept and prototype design.

#### 6.4 Embodiment design

This stage of the design process included the following: software development; electronic and mechanical design; materials specification and ergonomic design. Embodiment design resulted in the production of engineering drawings for prototype manufacture. Specific software was written for attaching to the evaluation VEs, so that the VE platform (Superscape) would recognise the inputs from the prototype. The electronic circuitry was designed for interfacing with the joystick (or games) port on a PC.

## 7. USER BASED ASSESSMENT

### 7.1 Introduction and objectives

Following concept and prototype design, the next step of the multi-disciplinary method was to conduct a user-based assessment of the developed VE input system. VR1 was to be compared against the JM system. The user-based observation for metrics method, outlined in the INUSE handbook of user-centred design (Daly-Jones, 1999), was utilised for this assessment. Evaluation objectives were:

- Evaluate the usability of VR1
- Compare the usability of VR1 and JM
- Identify whether VR1 meets the design requirements listed in the design specification
- Identify any usability difficulties with VR1 and suggest refinement.

### 7.2 Experimental Design

The following hypothesis and conditions formed the experimental design:

**Hypothesis:** The employment of the multi-disciplinary design methodology results in the design and development of a VE input system for young people with moderate to severe learning disabilities, which has greater usability than a commonly used system for this user population.

**Experimental condition:** the user group is observed using VR1 to control navigation and interaction tasks.

**Control condition:** the user group is observed using the JM system to control VE navigation and interaction tasks.

### 7.3 Method

Participants with the following characteristics were selected for the study:

**Participants:** 14 subjects.

**Gender:** 10 male, 6 female.

**Age range:** 7-19

**Cognitive ability:** the majority of the pupils have severe learning disabilities. A few are bordering on moderate learning disabilities.

**Physical ability:** the pupils have moderate physical disabilities, including co-ordination, gross-motor and fine-motor difficulties. One pupil uses a wheelchair.

### 7.4 Tasks

A range of tasks were set in the Virtual Factory and Supermarket. Factory: entering building, putting on protective clothes, reporting oil, ladder, trolley and first aid kit, going upstairs, putting containers away and leaving the factory. Supermarket: Enter, select pineapples, oranges, tomatoes, milk cartons, cereal, tea and coffee, ice-cream and then go to check-out.

### 7.5 Usability Metrics

Guiding principles for the requirements of non-keyboard input devices were selected for usability attributes (ISO 9241-9 European Standard as follows: obviousness, predictability, consistency, compatibility, efficiency, effectiveness, feedback, satisfaction, controllability and biomechanical load.

### 7.6 Results

The results for VR1 for the comparison of overall usability and the individual attributes of usability (excluding biomechanical load) all showed that VR1 scored greater than JM. The most significant result was for overall usability, as the majority of users were observed to find VR1 more usable than JM, with  $P=0.008$ . Further significant results were found for satisfaction and controllability, with VR1 having a significant advantage over JM. For efficiency and effectiveness, the results were only slightly better for VR1 and hence not significant.

Some attributes from the design specification were not met by the VR1 prototype. It is expected that, if all the device attributes from the design specification are employed in VR2, the efficiency and effectiveness, and hence overall usability, will improve.

## 8. CONCLUSIONS

The employment of the multi-disciplinary design methodology has resulted in the production of a VE input system that has greater usability than the more commonly used joystick and mouse. This finding could have relevance to other VE applications such as VEs for TBI patients (Davies et al, 1999) or for people with Asperger's Syndrome (Parsons et al, 2000), to enable selection and development of appropriate input devices to specific user populations. Continual application of the methodology could result in a database holding a range of suitable input devices for use by people with various disabilities using VEs. This database concept relates to the optimal VE access solution proposed by Brown (Brown et al, 1997): where the optimal solution would be to recommend a series of navigation and interaction devices that would allow people with a range of cognitive and physical disabilities to access VEs with ease and control.

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# ICDVRAT 2002

## Session VII. Training and Assessment

Chair: Albert Rizzo



# Virtual environments in cognitive rehabilitation of executive functions

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## ABSTRACT

The V.E.Ne.Re. Project (Virtual Executive NEuropsychological REhabilitation) consists in the construction and validation of artificial environments based on Virtual Reality (VR) technologies, aimed for cognitive rehabilitation of executive functions (frontal lobe dysfunction; dysexecutive syndrome). Damasio (1994) pointed at the discrepancy between non immersive artificial lab tests and real life situations to explain the frequent diagnostic and therapeutic failures that occur when traditional cognitive tools are used with frontal patients. In this perspective, VR environments which are capable to generate a better subjective perception of presence and immersivity, become a very promising alternative to enhance cognitive neuropsychology of executive functions. On these premises, we will describe the current three components of V.E.Ne.Re., with special regard to the V-Store software, which consists in a set of tasks aimed to empower executive functions, attention, short term memory, behaviour control and metacognition. V-Store is planned to offer a high level of interaction and to induce time pressure, eliciting subjective managing strategies. The same environment will be used to implement also the virtual versions of two well-known cognitive tests: V-ToL (VR version of Shallice’s Tower of London); V-WCST (VR version of the Wisconsin Card Sorting Test). We are currently starting to test our environments, with regards to their clinical efficacy, cost/benefit effectiveness, subjective experience and usability.

## 1. TARGET: DYSEXECUTIVE SYNDROMES

In the field of disabilities, the category of cognitive dysfunctions can be classified making a distinction between the loss (partial or complete) of the basic *instrumental* cognitive functions (such as attention, memory, language, visuo-spatial abilities, etc.) and the loss of *executive* functions (also called *central* or *control* functions). These are generally referred to a group of behavioural skills that includes: the ability of planning a sequence of actions, the ability of maintaining attention in time, the ability of avoiding the interfering stimuli and using the feedback provided by others, the capability of coordinating more activities together at the same time, the cognitive and behavioural flexibility and the other abilities used to cope new situations and stimuli (Crawford, 1998).

Many terms have been used to define this syndrome: *Disorders of Executive Functions*; *Dysexecutive Syndrome*; *Strategy Application Disorder* (SAD); *(Pre)Frontal Syndrome*. Loss of executive functions is primarily a consequence of brain injury located in the prefrontal cortex area, but many different categories of subjects can be characterized by the same syndrome and by similar symptoms, with different levels of severity and various forms of resulting behaviour: patients suffering of different forms of dementia (Alzheimer Disease, Frontal or Fronto-Temporal Dementia, etc.), patients with attention disorders and hyperactivity (i.e. ADD-H), subjects suffering of Schizophrenia or Psychopathy.

Usually the problems related with cognitive disabilities are not evident: Thimble (1990) noted that the pathological conditions due to a frontal dysfunction very often usually are not recognized in the clinical practice. This happens because in the case of frontal lobe disease, cognitive performance of subjects may not be severely reduced and because many traditional neuropsychological test may fail to show significant dysfunctions in the patients' answers (Damasio, 1994; Gourlay et al, 2000; Riva, 1998). As Damasio brilliantly pointed out, in the complex tasks of everyday life, the same patients may show great limits, decisional problems and inabilities connected with high levels of psychosocial suffering. It has been demonstrated that traditional tests of frontal lobes function may fail to document abnormality: this "diagnostic insensitivity" may cause problems between patients and health care services and can determine incapacity to predict the outcome of treatment.

Damasio's famous patient Elliot not only had normal performances in the standard "frontal" cognitive tests, but in the lab he was also able to elicit normal responses to the proposed social situations, he planned strategies and he demonstrated to be able to evaluate correctly the consequences of actions in social situations. The same patient showed a severe decisional impairment and emotional disregulation in his real life environment, especially related to social situations. Elliot is described as the prototype of the hi-functioning frontal patient who experiments severe problems in his daily life.

From the point of view of cognitive rehabilitation, if we consider that the traditional protocols used in treatment are centered mainly to protect or recover the basic instrumental cognitive functions, we can understand why, in a clinical or lab setting, superior executive cognitive disabilities are today particularly hard to treat and thus receive a very reduced attention in relation to their dramatic real-life consequences.

From a theoretical point of view, we can try to explain the striking differences in performance and behaviour between lab and life as result of four main failures of the artificial situations to mimic reality: a) choices and decisions are only to be evoked, not to be really performed; b) lack of the normal cascade of events as actions and reactions; c) compressed temporal frame; d) situations are not really presented, but only described through language (Damasio, 1994). In other words, our diagnostic and rehabilitative tools, built to be used in clinical or laboratory settings, fail their goal with executive functions because they cannot adequately reproduce real situations and the perception of the subject to be really *present* in them. Cognitive assessment and rehabilitation of executive functions faces us with the necessity to transfer our work in real life situations or, as a valid alternative, to be able to build artificial environments who can offer to the subjects similar conditions and the same sense of presence.

## **2. VIRTUAL REALITY AND THE SENSE OF PRESENCE IN CLINICAL APPLICATIONS**

Virtual Reality (VR) is considered as the most advanced evolution of the relationship between man and computers (Vincelli et al., 2001). VR is different from other technologies because it offers to users the chance to experience psychological states of *immersion* and *involvement* (Rizzo et al., 1998) due to the combination of hardware and software tools with particular interactive interfaces (such as *head-mounted display* and *tracker*). So one of the possible added values of Virtual Reality (with respect to traditional electronic systems of representation and interaction) seems to be the particular level of *presence* that subjects can experience in virtual environments (VEs). With the present and future development of technologies, synthetic environments will be able to re-create situations more and more similar to the ones we experiment in everyday life, therefore we can easily imagine that the possibility to feel presence in virtual environments and to use this technology in many fields will always increase.

Virtual Reality is a technology used in many applications, from health care to arts, from e-learning to entertainment. Focusing on the health care field, VR finds a role in many areas such as psychotherapy (assessment and treatment of pathologies such as social phobias, eating disorders, sexual disorders, depression, autism, etc.), cognitive rehabilitation (about memory, attention, spatial abilities and superior cognitive functions), motor rehabilitation (about paraplegia, tetraplegia, parkinsonism and other disabilities). In particular, in the field of rehabilitation, the possibility to use new technologies has been studied (Gordon et al., 1989) and the potential of virtual reality based applications has been recognized (Pugnetti et al., 1998; Rizzo & Buckwalter, 1997a).

According to Rizzo et al. (1998), it is necessary to carry on a realistic cost/benefit analysis to evaluate which is the added value of VR in different applications comparing with traditional approaches. A key

question is “does the objective that is being pursued require the expense and complexity of a VE approach, or can it be done as effectively and efficiently using simpler, less expensive, and currently more available means?”.

There are different issues to consider in order to evaluate the real costs and benefits of Virtual Reality in mental health applications. One of these important issues, in order to ensure high benefits in the use of VR, is represented by production of functional and useful environments. Traditionally, as indicated by Waterworth & Waterworth (2001) “VR designers typically aim to create a convincing, engaging, environment in which users feel present”. The focus for VR developers seems to be “presence” and all the systems to improve it.

But the concept of presence is very complex because this psychological state is characterized by many factors and so a key issue becomes the choice of the presence factors that have to be considered in the use of VEs in mental health applications. Riva (2000) notes that the substantial challenge for the designers and users of VR is *how to use immersive environments to support clinical practice*. It becomes clear that a VE built for entertainment has to be different from a one use in psychotherapy or cognitive rehabilitation. So which are the core characteristics of a virtual environment in order to ensure a kind of presence that is functional and useful for mental health applications?

In Riva's opinion two key characteristics of VR as a clinical oriented tool have to be the *perceptual illusion of non-mediation* and the *sense of community*: in mental health applications reproducing physical aspects of virtual environments may be less important than the possibility of interaction that a VE could allow. According to Riva, in clinical oriented environments “the criterion of the validity of presence does not consist of simply reproducing the conditions of physical presence but in constructing environments in which actors may function in an ecologically valid way” (p. 356). Thus the level of presence, connected with the functional use of VEs in clinical applications, depends also on the level of interaction and possible interactivity (Riva, 2000; Smets et al., 1994).

### 3. OUR REASONS FOR A VR CHOICE

Cognitive rehabilitation has to allow patients to recover their planning, executing and controlling skills by implementing sequences of actions and complex behavioural patterns that are requested in everyday life (Rizzo & Buckwalter, 1997a, 1997b): with these conditions, VR can be specifically indicated to reach this goal (Rizzo et al., 2000; Grealy et al., 1999). Moreover VR allows to build realistic spatial and temporal scenarios that can be easily used to increase diagnostic sensitivity of standard paper&pencil tests (Pugnetti et al., 1995, 1998). For example, in the case of early recognition of Alzheimer's disease, VR may be the most efficient method for a systematic screening of subjects (Rizzo et al., 1998).

Due to the great flexibility of situations and tasks provided during the virtual sessions, considering both the time, difficulty, interest, and emotional engagement, this new technology allows, besides the diagnostic applications (Zhang et al., 2001), to enhance the restorative and compensatory approaches in the rehabilitating process of cognitive functions inside the traditional clinical protocol.

In our opinion, in general cognitive rehabilitation, the added value of VR compared to the traditional treatment can be summarized according to the following points:

- possibility to programme: each virtual environment can be produced in a specific way focusing on the patient's characteristics and demands;
- possibility to graduate: each virtual environment can be modified and enriched with more and more difficult and motivating stimuli and tasks. This last issue shall not be underestimated, because many subjects with cognitive dysfunctions have a low level of motivation and compliance about the traditional rehabilitating iter that is usually repetitive and not stimulating;
- high level of control: the possibility of controlling the rehabilitating process in its development is very high. This issue allows to professionals to monitor the level of affordability and complexity of the tasks that can be provided to patients;
- ecological validity: a virtual environment allows to stimulate in the subjects emotional and cognitive experiences like in the real life. So the tasks executed during the immersion in the VR can induce the patient to reproduce complex cognitive procedures (such as planning and organizing practical patterns of actions, attentional shift, etc...) that are similar in all the aspects to the ones used in the situations of everyday life;

**Table 1.** Possible issues to consider in designing Virtual Environments in clinical applications.

Key questions	Possible answers	Applications and indications for VR designers
1. Are VEs useful, effective and efficient in clinical applications?	Evaluation of possible advantages and limits Cost/benefit analysis	Development of VEs that have to ensure only the level (and quality) of presence requested by each application.
2. Do VEs reproduce the physical and perceptual characteristics of real environments?	Attention on graphics and technical characteristics. Focus on realism and technical issues	Development of VEs that have to ensure realism and a level of presence as non-mediation and immersion.
3. Do VEs allow users to function in an ecologically valid way?	Attention on cultural and social aspects. Focus on interaction, interactivity Importance of relationships and context	Development of VEs that have to ensure ecological situations of interaction, interactivity

**Table 2.** Synthetic description of the three components of V.E.Ne.Re..

Name	Goal	Brief description
<b>V-Store</b> <i>Virtual Store</i>	▪ rehabilitative	Virtual environment (internal store) in which the subject (clinical or experimental) has to solve a series of tasks ordered in six levels of increasing complexity. Tasks are designed to stress executive functions, behavioural control and programming, categorial abstraction, short-term memory and attention. A series of distracting elements are present, aimed to generate time-pressure and to elicit managing strategies. The examiner has full control on all variables, to enhance usability and to increase the number of sessions that a single patient will be administered
<b>V-ToL</b> <i>Virtual Tower of London</i>	▪ rehabilitative ▪ diagnostic	A virtual version of the notorious Tower of London Test by Shallice, using the same environment as V-Store. The test is meant to evaluate the executive ability to program behaviour in time. The original paradigm and trial sequence is carefully respected, to grant the clinical and scientific equivalence of results. The task can be used as a one-time assessing test or repeated as a rehabilitative tool (the examiner can intervene on all variables implied).
<b>V-West</b> <i>Virtual Wisconsin Card Sorting Test</i>	▪ rehabilitative ▪ diagnostic	A virtual version of the notorious Wisconsin Card Sorting Test (Heaton, 1981), using the same environment as V-Store. The test is meant to evaluate the executive abilities of categorization, abstraction and behavioural flexibility. The original paradigm and trial sequence is carefully respected, to grant the clinical and scientific equivalence of results. The task can be used as a one-time assessing test or repeated as a rehabilitative tool (the examiner can intervene on all variables implied).

- economical advantage: rehabilitation with VR can be cheaper than the traditional one, mostly when it comes to the reconstruction of complex scenarios, also of very complex ones (such as presence of more persons in the same time, particular environmental conditions), which avoids the need to leave the rehabilitation office or building.

Nevertheless, when it comes to the specific needs of rehabilitation of dysexecutive symptoms and frontal lobe syndrome, the employment of virtual environments appear to have another fundamental advantage with respect to traditional non-immersive means. According to Damasio (1994; see 1<sup>st</sup> par.) diagnostic and rehabilitative tools used in labs and clinics often fail to assess and treat the frontal patients because they operate within artificial situations, which are far from reproducing the real situations. In this view, immersive virtual environments appear to be the best solution to make lab situations become closer to the natural setting in the subject's perception.

For these reasons, in our work we decided not only to use and implement immersive virtual environments, but also to assess very carefully the key variables that support such choice: subjective sense of presence; qualitative evaluation of virtual experiences; usability level.

#### 4. DESCRIPTION OF THE V.E.Ne.Re. PROJECT

This project aims at planning, developing and testing a rehabilitating protocol with virtual environments for high-level cognitive dysfunctions that affect patients with brain injuries, cerebral diseases, degenerative pathologies and in particular subjects who can be evaluated as "frontal patients" in scientific literature. Even if the focus of this project will be overall centered on this last syndrome, we suppose that the applications which will be developed could be useful in a broad spectrum of rehabilitative opportunities.

The project will use the technology of VR systems. Due to the use of VR, the project aims at offering new solutions to reorganize the cognitive abilities in the subjects with disabilities in order to improve life quality, in the sense of a better control of behaviour and information processing.

The three components that are currently planned for programming and testing are described in Table 2.

The project will follow 5 steps:

- 1) *collecting of the real needs and demands of subjects with frontal syndrome using focus group and discussion group.* It will not be possible to use only a user-centered approach because of the possible distortion of the subjective judgment typical in patients with frontal deficits; so it will be necessary to create situations where to compare different points of view and to think over these issues between the professionals involved in the rehabilitation (neuropsychologists, neurologists, nurses, assistants, etc...). Using the focus and discussion group methodology, it will be possible to point out the different types and levels of cognitive disability and the most common psychological reactions in front of the suffering in order to define the application fields of VR. In particular a key issue will be the rehabilitation of the most complex cognitive functions (planning an action in all its different steps, distribution of attention towards more information in the same time, etc...), that are traditionally not considered in the standard rehabilitating iter;
- 2) *planning and realization of the virtual environments.* During this step of the project, it will be realized the planning and realization of new virtual scenarios and the tuning and functional adaptation of virtual environments already used in other applications (such as psychotherapy and motor rehabilitation). The goal of this step will be the construction of virtual environments where the subjects can carry out cognitive tasks similar to the ones that they already develop in different situations of everyday life. These environments will be characterized by gradual levels of complexity, control and feedback;
- 3) *analysis of the usability of virtual environments to simulate real tasks using normal subjects.* In this step, through the reports provided by normal subjects, it will be possible to evaluate the level of immersion, engagement and realism produced by the software that has been realized in the previous step. To have a measure of the subjective aspects of virtual experience, it will be used the Sense of Presence Inventory, which is going to obtain a validation also in Italy;
- 4) *use of virtual environment sessions within the traditional rehabilitating iter.* In this step the traditional protocol followed in the cognitive rehabilitation will be integrated with a session of interaction with virtual environments. It will be realized a comparison between the experimental group performances

(group composed by patients with frontal syndrome and VR enhanced treatment) and control group performances (group composed by patients with frontal syndrome and classical treatment without VR sessions). Two controlled clinical trials will be planned: the first one regards a small sample whereas the second one involves a large sample. The possibility to have results from the first small sample will allow to modify and tune the virtual environments for the second and larger clinical trial;

- 5) *evaluation of the efficacy of virtual environments in the rehabilitating iter.* This step aims at verifying the qualitative and subjective aspects of virtual experiences in the disabled patients. Moreover it will be evaluated the reached degree of rehabilitating efficacy and the perceived level of motivation related to the virtual experience. The qualitative evaluation of virtual experiences in the rehabilitating iter will be realized using a subjective questionnaire (in particular the QUEST, *Quebec User Evaluation of Satisfaction with Assistive Technology*). The data collected with this questionnaire will be necessary compared with other evaluations provided by the professionals involved in the rehabilitation (neuropsychologists, neurologists, nurses, assistants, etc.).

## 5. V-STORE: A REHABILITATIVE TOOL

The virtual environment consists of a fruit store internal room: the subject (or more correctly his “avatar”, his representation within the virtual world) is set in front of a conveyor belt on which some baskets (from one to three) cross the room. The subjects’ task is to fill up the baskets with pieces of fruit that can be found in four shelves located on the other walls of the room.

At the beginning of each trial, a verbal command is communicated through a loudspeaker, located on the front wall, by which the subject is instructed about what to do: how to fill the baskets and with what kind of fruit. The task has to be completed accurately before the baskets run out of the room on the belt, or else the trial will be repeated from the beginning. It is possible to fix a maximum limit in how many “moves” the subject can execute to solve the trial, forcing him to follow the most efficient and quick strategy.

The tasks are ordered according to their complexity, starting from very quick trials that need few fruit moves, up to trials that start with a long and verbally complex command and request special strategies in moving the available fruits from one basket to another. The trials are currently divided in six levels of ten tasks each.

Other elements which are present in the environment are a waste basket, the light switch and a wall telephone, located on the rear wall, through which the subject can receive supplemental orders that integrate the initial verbal command in the most difficult level. The subject can intervene on some additional commands, by which he can stop the belt, end the trial, freeze time.

The supervising examiner can introduce a series of distracting events which increase difficulty and are meant to generate time pressure (Fasotti et al., 2000): room light fainting or progressive dimming, telephone ring, belt speed modification. In these situations, the most interesting focus of performance and rehabilitation consists in the managing steps that the subject will operate and his strategic approach.

For each trial, the system records the following data about the subject’s performance for further analysis or research: accuracy, execution time, moves and strategical planning, and furthermore the managing steps taken to face distractors or difficulties, which often constitute the greatest limit for frontal patients.

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# Adaptable virtual reality interface for powered wheelchair training of disabled children

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## ABSTRACT

Childhood development is directly related to being able to independently explore, manoeuvre and interact with one's environment. However, severely disabled children having motor dysfunction often experience impeded motor development, and consequently lack independent mobility. This work relates to the development of the Virtual Environment Mobility Simulator (VEMS) to provide a simple and cost effective choice for powered wheelchair training and rehabilitation. The current area of interest is to study the effects of using real-time wheelchair motion as input for interacting with the home environment. This system provides a home environment delivered on a flat screen computer monitor, and offers simple tasks along with game elements to motivate the user. The widely varied nature of disability, however, requires adaptability of the virtual reality system to specific user training needs. In this paper we propose a conjoint analysis technique to analyse user behaviour, preferences and disability to gear towards the needs of providing an effective training.

## 1. INTRODUCTION

Childhood development is directly related to being able to independently explore, manoeuvre and interact with one's environment. This idea is now widely accepted amongst, social scientists, cognitive psychologists, and early childhood education specialists. Over the years, several published works have emphasized the importance of independent mobility to a child's developmental process (Rosenbloom, 1975; Bertenthal et al., 1984). It has been noted that spatial perceptual and cognitive abilities are developed during self-locomotion. Spatial perception encompasses the ability to localize one's self in space, depth perception, shape recognition, visually guided reaching, awareness of self-motion, as well as cognitive mapping and problem solving in multidimensional space. Cognitive mapping is a vital developmental "process composed of a series of psychological transformations by which an individual acquires, codes, stores, recalls, and decodes information about the relative locations and attributes of phenomena in there everyday spatial environment" (Downs and Stea, 1973). Independent mobility, or self-locomotion, is highly dependent on human motor development. The experiences needed for the development of motor skills are best gained through progressive learning and training, in the early years of life. However, severely disabled children having motor dysfunction often experience impeded motor development, and consequently lack independent mobility. Thankfully, in order to replace some of the developmental experience that may otherwise be lost in disabled children, several research works have been focused on the training of severely disabled children to use powered wheelchairs safely and functionally (Furumasu et al., 1996; Nisbet et al., 1996). Accordingly, the use of virtual reality (VR) technology in the training and rehabilitation of powered wheelchair users have been researched (Inman et al., 1995; VanSickle et al., 1995). This is largely due to the several advantages that VR offers. VR offers safe and risk free training environments that requires less effort and cost, relative to other training method. Motivation factors can be introduced more effectively in the virtual environments.

In view of this, in the last four years, our group at the University of Limerick has focused its attention in researching the use of virtual reality technology to deliver a (non-immersion type) three-dimensional graphics environment on a computer workstation (Desbonnet et al., 1997; Cox et al., 1999). Two virtual

environments were initially developed. These environments were explored using a wheelchair DX-joystick interface. Severely disabled children at St. Gabriel School, Limerick benefited immensely from the fun elements incorporated into the environments. In turn, the experience of working with these children has widened the research scope opening pertinent areas needing attention. Thus, the current area of interest is to study and assess, by an experimental method, user interaction and performance in the virtual environment. Hence, the current stage of development in our Virtual Environment Mobility Simulator (VEMS) suffices for this study.

It has been generally established that there is correlation between training in a VR environment and real world training (Standen and Cromby, 1995; McComas et al, 1998). The widely varied nature of disability, however, requires adaptability of the virtual reality system to specific user training needs. In this paper we propose a conjoint analysis technique to analyse user behaviour, preferences and disability to gear towards the needs of providing an effective training. This therefore requires the monitoring of preferences and behaviour, and the creation of individual user profile based on experimental data.

## 2. OBJECTIVES

The long-term goal of this research is to deliver a simple and cost effective choice for wheelchair training and rehabilitation using virtual reality technology. The ultimate approach is to help the children to learn while they play, or play while they learn, in the virtual environment. Perhaps the skills learnt will be transferred from virtual reality into real world settings. In harmony with this goal, our immediate objectives are

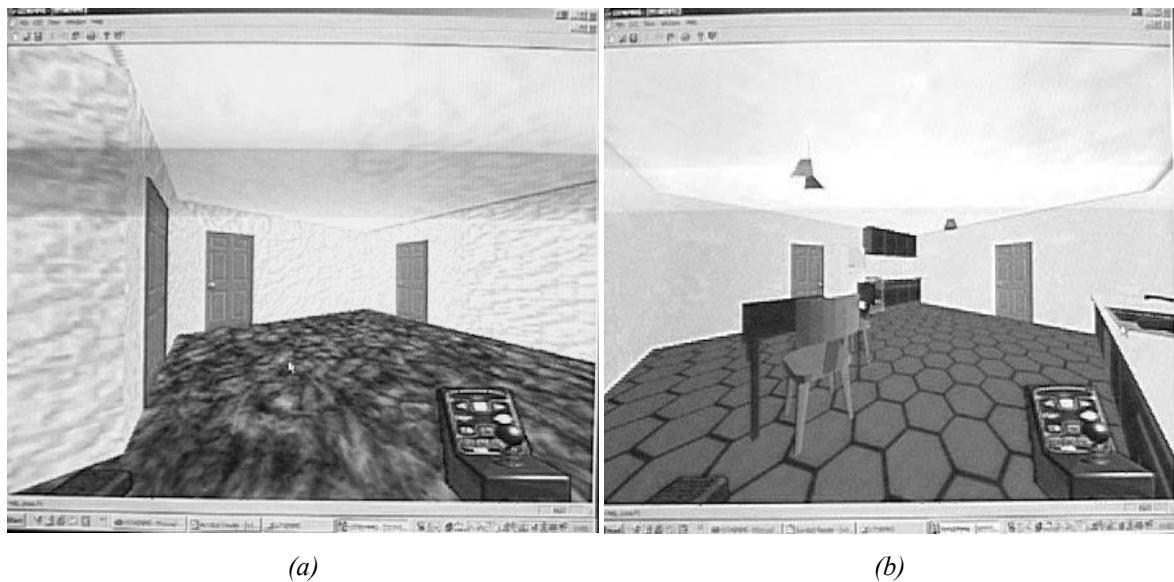
- To investigate an experimental method for the assessment of user interaction and training performance in the virtual environment.
- To ascertain the effectiveness of using the wheelchair motion as an input for interaction and training.
- To adapt the VR environment to user preferences, disability and training needs in order to provide a more effective training environment.

## 3. APPLICATION DEVELOPMENT

The work done to date required the development of the Virtual Environment Mobility Simulator (VEMS). This system entailed two design elements—the software and hardware developments.

### 3.1 Software Development

This involved modifications to the existing home environments developed by the research group. The development involved the use of three software packages, AutoCAD 2000, WorldToolKit (release 9) and Microsoft Visual C++ (version 6.0). AutoCAD 2000 was used for construction and modification of existing 3D virtual objects. WorldToolKit (release 9) provided a C/C++ language library of functions that can be coded in Microsoft Visual C++ (version 6.0) for dynamic manipulation of the virtual objects. Also, Microsoft Visual C++ (version 6.0) provided the platform for compiling and executing the program at run time. The home environment developed using this software packages included a bedroom, bathroom, living room, study, and kitchen with connecting corridors. This environment is delivered on a flat screen computer monitor, and offers simple tasks along with game elements to motivate the user. The screen displays two windows, the large window and the bird's eye window, for viewing the environment. The large window holds the real-time location of the user view during motion within the virtual environment. The bird's eye window can alternate between a static view and a dynamic view. The static view observes the position of the wheelchair object from the house plan. And the dynamic view tracks the position of the wheelchair object from the rear. The VEMS will eventually be programmed to record and replay the path followed by the wheelchair object in the virtual house. At this stage of development, the mouse can be used as the motion input to the wheelchair object travelling through the home environment. Also the mouse allows for disabling and enabling of other input devices, thereby providing the therapists with absolute control over the system. Figure 1 shows the screen shot of the hallway and the kitchen in the VEMS house environment.



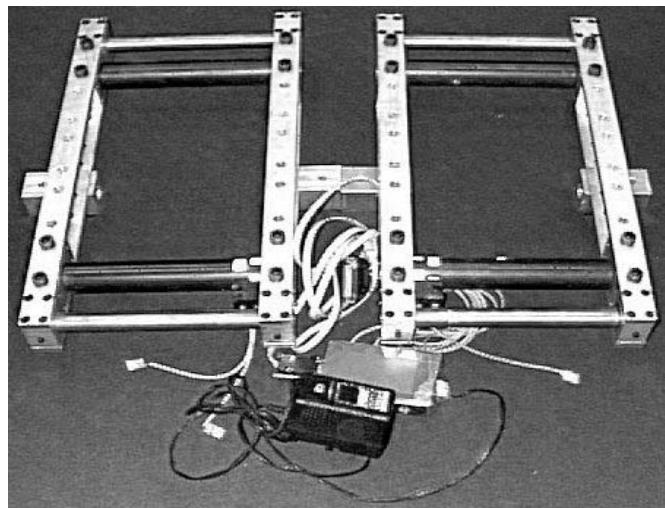
(a)

(b)

**Figure 1.** User View of the VEMS House Environment: (a) Hallway (b) Kitchen.

### 3.2 Hardware Development

The element of the VEMS development involves the design and construction of a wheelchair platform incorporating a roller unit. This roller unit is the functional part of the platform designed to serve as a mechanical interface between the wheelchair and the computer. The roller unit was designed to keep the wheelchair stationary, while allowing the rotation of the wheels. This unit consists of two pairs of rollers (shown in Figure 2), each fitted with reflectors and sensors to track the motion of the wheelchair. Digital signals are obtained from the sensors as the wheels rotate. And the principle of odometry is applied to determine the components of translation and rotation for the wheelchair transformation in the real world. The roller has been tested and it provides the reading of the exact distance travelled by the wheelchair in the real world. This facilitates the accurate determination of the appropriate speed involving the translation and rotation of the wheels. Consequently, this transformation is applied to the simulation of the wheelchair object in the virtual house. An alternative hardware input device that can be interfaced to the computer for motion tracking is a standard wheelchair joystick.



**Figure 2.** Functional (roller) unit of the wheelchair platform.

## 4. EXPERIMENTAL METHOD

The task of analysing preferences and behaviour is based on conjoint measurement method. Conjoint analysis presents experimental and statistical techniques for the measurement and prediction of consumer preferences or choices for product or services. It has proven useful to academic and professional researchers in the past

25 years. Experimental designs in conjoint study often involve the design and analysis of hypothetical decision tasks requiring the subjects, or respondents, to make judgements. Thus, conjoint measurement theory investigates the functional relationship between multi-attribute stimuli and the subjective value as perceived or expressed by the respondent. Multiple hypothetical alternatives, for product or services, can be presented in harmony with the principles fundamental to the design of statistical experiments. The fundamental interest of a conjoint analyst lies in the composition rule that allows the consumer to aggregate the utility associated to each attribute to yield the value or importance attached to a product or service. This rule, known as *preference model*, facilitates the development of simulation models that can be used to predict consumer choices for future product and services. Utility (or part-worth) here refers to the index number or coefficient representing the weight a subject places on a particular attribute or feature in a given product or service. Thus, given an assumed preference model, the importance of each attribute-level combination can be estimated based on the explicit preference measures for each of several alternative products. Traditionally, most conjoint experiments involve verbal presentations of hypothetical alternatives, while some have been pictorial.

Virtual reality, on the other hand, can combine both verbal and pictorial presentation formats with significant improvements to the realism of hypothetical alternatives. An outstanding advantage of virtual reality for the purpose of presentation is to provide the subject with an improved feeling of product realism, through visually active involvement, before any choice or preference is made (Dijkstra et al, 1996). VR technology facilitates the development of immersion and non-immersion environments that allow the subjects to experience the advantages, or otherwise, of the various features proposed in the modifications to products or services. VR will allow the observation and recording of subjects' reaction to alternatives for the purpose of evaluating their preferences, even into the future. Conjoint analysis will be applied to measure and predict the action or reaction of respondents to combinations of stimuli in varying hypothetical scenarios. Since the objective is to evaluate powered wheelchair-driving skills, hypothetical settings involving multi-attribute alternative scenario designs are being investigated. It is proposed that a preference model of performance can be obtained for each user.

#### 4.1 Experimental Design

The subject (i.e. wheelchair trainee) will be required to accomplish a combination of simple tracking tasks making up a scenario. Each tracking task will test a wheelchair-driving skill. For the purpose of this experiment, in accord with the design requirements for conjoint analysis, some of the basic driving skills of interest necessary for the control of powered wheelchair are described as follows:

- Forward Motion – Ability of the user to drive wheelchair forward when prompted in the virtual environment.
- Reverse Motion – Ability of the user to drive wheelchair backward when prompted in the virtual environment.
- Left control – Ability of the user to accomplish a left-turn task while exploring the virtual environment.
- Right control – Ability of the user to accomplish right-turn task while exploring the virtual environment.
- Speed – Ability of the user to respond to changes in the speed of task presented in the virtual environment.
- Stop – Ability of the user to respond to stop signs in order to avoid collision with specific object in the virtual environment.

For conjoint analysis these driving skills are the attributes, and the scenarios are the hypothetical alternatives. Since each attribute is presented as one of six possible tasks in a given scenario, and given six scenario levels, 46656 (i.e.  $6^6$ ) hypothetical scenarios can be generated for full factorial design. However, the fractional factorial design is favoured for the experiment. Thus, 6 hypothetical scenarios may be selected for the experiment. Table 1 provides the design specification for 6 multi-attribute hypothetical scenarios.

#### 4.2 Experimental Procedure

A game environment incorporating features of the real world will be presented to respondents. The respondents are required to accomplish simple tracking tasks within the virtual environment. These tasks involve driving the wheelchair to hit several primary and secondary target objects positioned in various places within the rooms of the virtual environment.

**Table 1.** *Experimental Design Specification for Six Hypothetical Scenarios.*

Attributes	Scenario 1	Scenario 2	Scenario 3	Scenario 4	Scenario 5	Scenario 6
<b>Forward Motion</b>	Task No. 1	Task No. 2	Task No. 3	Task No. 4	Task No. 5	Task No. 6
<b>Reverse Motion</b>	Task No. 2	Task No. 3	Task No. 4	Task No. 5	Task No. 6	Task No. 1
<b>Right Control</b>	Task No. 3	Task No. 4	Task No. 5	Task No. 6	Task No. 1	Task No. 2
<b>Left Control</b>	Task No. 4	Task No. 5	Task No. 6	Task No. 1	Task No. 2	Task No. 3
<b>Speed</b>	Task No. 5	Task No. 6	Task No. 1	Task No. 2	Task No. 3	Task No. 4
<b>Stop</b>	Task No. 6	Task No. 1	Task No. 2	Task No. 3	Task No. 4	Task No. 5

In order to motivate the trainee, visual and audio cues will be given for successes. This will include visible scoring of successes. They will be penalised with a reduction in score for hitting the wrong objects such as room wall, chair, table, etc. Further, for conjoint analysis, the trainee will be scored accordingly for each primary or secondary target objects successfully hit while accomplishing the tracking tasks. This will help determine the preference score for each multi-attribute scenario level and their attribute utilities, respectively. The steps involved in the evaluation of the users are described as follows:

**4.2.1 Experimental Sessions:** Two experimental sessions will take place. The first session will allow the selected pupils to play the game in the VE for as long as they can bear. This enables the determination of the minimum duration for the second experimental session. The results from the first experiment will be used to obtain several simulations of sample data required for resolving vital issues involving the set-up of the second experimental session. More importantly, the first experiment will enhance the investigation of the key issues of interest in a subject, so that the second experimental session can be modified appropriately. Hence, the second experimental session will be used to create a detailed profile of the pupil for future training modifications.

**4.2.2 Simulation:** Several issues need to be investigated in order to obtain consistent experimental results required for modelling performance and, ultimately, to create detailed profile for the user. These issues include the determination of sample size required for a particular user, the number and selection of appropriate hypothetical scenarios, the determination of the subject's possible weak driving skills, etc. However, in order to reduce unnecessary fatigue on the disabled user when obtaining the experimental data samples required, it is possible to carry out several simulations of data samples based on the first experimental results. Thus, the simulation will facilitate the introduction of necessary features to the second experimental session, and adaptation of the training sessions to suit the subject.

**4.2.3 Profile.** In order to provide an effective training for a disabled child using VR scenarios, a detailed understanding of the subject's behaviour regarding various stimuli is important. Such understanding will enable the creation of user profile to check the correlation between their disability and training performance. This will certainly guide a rehabilitation specialist towards more focused and improved training. Thus, conjoint analysis provides a means for studying the action or reaction of subjects to combinations of stimuli in varying hypothetical scenarios.

Since the objective of this work is to evaluate powered wheelchair-driving skills, the content of the user profile for this research focuses on factors involving direction (forward, reverse, left- or right-turn) control and the user response when prompted to change speed or stop. For example, it should be possible to determine a child's weak driving skills, the relative importance of a particular skill in relation to others and how specific skills affect the actual user performance. Likewise, an understanding of the subject's action or reaction to a given task can be profiled. For example, does the child move the wheelchair joystick backwards when tasked to move forward? This will certainly have negative effect on the related attribute utility. Further, the profiled driving skills will be better refined in consultation with the therapists. Indeed, the focus of any user profile in a conjoint study will vary from one researcher or specialist to another.

## 5. DISCUSSION

Traditionally, conjoint analysis has been a multiple regression problem. The multiple linear regression equation can generally be given as shown in equation (1) below. In ANOVA, the respondent's rating for the hypothetical alternatives provides the dependent variables used in the statistical analysis. And the attribute levels serve as the independent variable. The estimated  $\beta$  coefficient associated with each independent variable is the utility for that specific level.

$$Y = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_N X_N \quad (1)$$

where  $Y$  = the dependent variable

$X_N$  = the  $N^{\text{th}}$  independent variable

$\beta_N$  = the regression coefficient for respective independent variable

$N$  = Number of possible observations of the independent variable

Although several statistical methods exist for conjoint analysis, the type of data collected, and the subjects of interest in the analysis often determine the regression technique used. Further, the technique applied is usually a reflection of the algorithmic differences and alternative approach to data collection and measurement. It is of interest to examine the correlation between a subjects' response and that predicted. Validation of preference model for overall fit is vital. In other words, it is necessary to check the goodness-of-fit of the derived model in comparison to the actual performance. This will help check the effect of introducing new or adapted alternative scenarios to the training system.

In conjoint analysis, measurement error can be reduced by large amount of sample data. However, the subjects can become fatigued, and there is a limit beyond which responses are no longer reliable. The situation may be hindered further by the condition of the disabled. They may not have the needed energy and patience to provide a large amount of sample data. Thus, it is important to strike a reasonable balance between overworking the respondents (yielding noisy data) and not having enough data to significantly obtain stable estimates. For investigational work and development of hypothesis in market research, a sample size of 30 to 60 has been recommended (Orme B., 1998). It is therefore useful to investigate this issue for the VEMS training experiments.

**Table 2: Example Preference Scores for 4 Hypothetical Scenarios**

Sample	Scenario 1	Scenario 2	Scenario 3	Scenario 4
1	5	2	4	6
2	2	6	5	4
3	4	5	5	5
4	6	1	5	4
5	2	8	6	5
6	5	5	7	7
7	7	4	8	7
8	2	1	8	5
9	5	7	3	5
10	8	5	3	6
11	3	3	6	4
12	5	8	4	6

In view of this, the procedure to carry out several simulations based on the first experimental result should prove effective for the modifications of appropriate parameters during the second experiment. For example, if the sample data provided in Table 2 represents the preference scores for a particular subject after the first experiment. Assuming these preference scores for 4 hypothetical scenarios are based on a scale of 1- 10. It can be observed from the sample data for scenario1 that the preference scores ranges between 2 to 8. Also, the preference score range changes from one scenario level to another. Thus, it is possible to generate preference scores that take into account the first experimental results regarding the range and consistency of preference scores in each scenario level. The same procedure will be applied to attribute utilities. As noted in the table above, the maximum size obtained for the trainee is 12. By generating the required data, it is possible to determine if fewer or more samples will be required to stabilise our estimates in the second experiment.

Consequently, a software program has been written to generate a large amount of sample data (i.e. preference scores, attribute utilities) for as many scenario levels as may be required, and to simulate parameters relevant to the design of experiments using conjoint analysis. This program is currently been tested.

## 6. CONCLUSION

This work proposes a technique for monitoring and adapting a VR training system to user needs and disability profiles. This research work is directed towards showing that user performance is measurable during training in the VEMS. And the potential benefits of the proposed approach may prove significant to future research in rehabilitation.

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# Flexible and virtual travel training environments

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## ABSTRACT

This paper describes the development and evaluation of a virtual travel-training environment for use by people with a learning disability in developing employment related skills. This environment has been designed to work in conjunction with a mobile agent to provide a comprehensive system to prepare and provide real time assistance to people with a learning disability. The evaluation of the virtual travel training environment via a series of case studies has allowed us to advance the development of previously published design guidelines for virtual environments for use by this user group. The next stage of this study is to obtain baseline assessment of the use of these environments before the design and implementation of a range of virtual tutoring agents. Subsequent evaluation of the enhanced environments will allow us to determine the efficacy of such tutoring agents.

## 1. INTRODUCTION

This is not the first virtual reality based travel-training environment to be developed. VIRTRAN was developed for a Supported Employment Scheme in the United States (Brown, 1997). This has been followed by a virtual learning environment developed within the Virtual City, to teach independent living skills to people with a learning disability (Brown, 1999), together with a number of other initiatives in the provision of independent travel support for people with a disability (Risser, 1993).

The Virtual Transport System within the Virtual City was designed as a way of physically linking the other three Virtual Learning Environments (VLEs) including the Virtual Café, House and Supermarket. Thus, the tester could take the bus from the house to the supermarket, or to the café, and so on. The bus route was not modelled on any actual location but the buses themselves were made to resemble Nottingham City buses. A snapshot from this virtual travel-training environment is shown in Figure 1.



**Figure 1.** The virtual travel training component of the Virtual City.

More recently a travel training package has been developed to train people with learning disabilities to use public transport to access employment in connection with the Mencap organised Enter2000 conference held at the Millennium Dome, London (Lewis et al, 2000). To achieve this aim a user group of people with learning disabilities was formed in South East London, the area from which the Mencap Employees were drawn. A snapshot of this virtual travel-training environment is shown in figure 2. This group were supported

by mentors and a facilitator, in line with the development of other adaptive learning environments for the disabled (Kurhila, 1998).



**Figure 2.** The virtual travel training environment to the Millennium Dome (from Presence).

One important feature of studies to investigate the efficacy of these and other related virtual training environments is evidence demonstrating that experience gained in using them can transfer to real world competencies, and that people with a learning disability are motivated to use them and can gain confidence in doing so (Standen et al 1998, Brooks et al 2002, Rose et al 2002).

The evaluation results from the Virtual City and Millennium Dome studies has led to the further application of this technology to the travel-training of people with learning disabilities. Systematic evaluation has also led to the distillation of design guidelines for the development of virtual training environments aimed specifically at this target group. These design guidelines feed the continual refinement of the user-sensitive design methodology employed in this project.

## 2. AIMS OF PROJECT

The current project recognises that travel training is an integral part of pre-employment training, but is lengthy and highly labour intensive. New electronic communication systems provide an opportunity to develop a much more cost-effective solution to helping people to travel to work independently. Two different, but integrated approaches to the use of such electronic systems are being developed and tested. The first involves the development of a virtual travel training environment; the second the use of handheld, portable computerised communication aids.

It is intended that the virtual travel-training component will be as constructivist in nature as possible. Many virtual training environments developed so far for use by people with learning disabilities have resorted to embedding a large number of procedural activities. Whilst breaking down important life skills activities into set sequences is important for a group of people who are frequently termed concrete thinkers, adherence to these principles can produce virtual learning environments which are over 'linearized'. Repetitive use of these training resources can result in disaffected learners. The aim of the current programme is to produce virtual training environments with global traffic variables, such as differing road layouts, traffic densities, and variable road crossing positions, so that each training session provides a truly new learning situation. In this way trainees will construct travel-training skills in collaboration with their mentors.

## 3. METHODOLOGY

The user-sensitive development and evaluation methodology used to ensure user participation in all stages of this project draws heavily from one used extensively in other, related projects (Brown, 2002). It is similar in

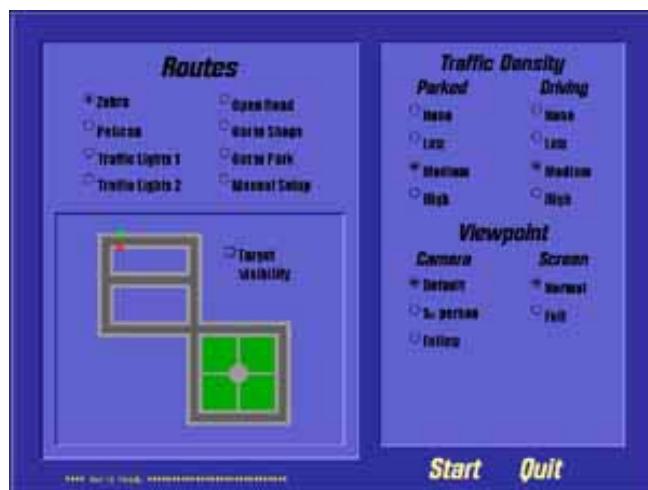
nature to the generic 'spiral' method used extensively in software engineering. The general steps are as follows:

1. Form Project User Group: Users from Sutton with learning disabilities will input their ideas on the design of the travel training package working together with a facilitator.
2. Storyboarding: The design ideas of the User Group will be converted to storyboards to guide the development of the travel training package. These draw heavily upon existing design guidelines (Brown, 2000).
3. Implementation: The storyboards will be converted into a Virtual Travel Training Package, using Macromedia Director 8.5 to create the virtual environment and 3D Studio Max to create the models.
4. Evaluation: The Virtual Travel training Package will be assessed by members of the Sutton User Group to evaluate programme usability and efficacy of embedded virtual tutoring agents.
5. Refinement: The results from the evaluation process will be used to refine the Virtual Travel Training Package to ensure that it will be fit for purpose. Further design guidelines may evolve.

#### 4. IMPLEMENTATION

The Sutton travel-training package has been designed to assist people with learning disabilities to learn independent travel skills. These competencies can enhance their opportunities to access training or employment opportunities to promote their social inclusion. Figure 3 shows this training package's starting interface, facilitating constructivist learning. The learning objectives have been identified by the project User and Steering Groups as below:

- Crossing the roads safely
- Personal safety issues
- Route finding to various destinations.



**Figure 3.** Travel training interface.

Members of the User Group undertake three tutorials in the following manner.

##### 4.1 Tutorial one: Zebra crossing

In this tutorial, the learner can adopt first person or third person perspective (avatar) starting at the zebra crossing. (Figure 4). Keyboard, mouse or joystick control can be adopted. The learner should cross the road observing the safety routines, such as standing beside the road, looking left and right till the cars stop then crossing the road without stepping outside the zebra crossing.

##### 4.2 Tutorial two: Pelican crossing

This tutorial has been identified as mid-level skill to help the learner to cross pelican crossings safely (Figure 5). The learner learns to cross the road to the opposite corner of the street by crossing two sets of pelican crossings, observing the procedures and safety rules, such as pressing the pelican button and waiting until the light turns green, then crossing the road without stepping outside the crossing.

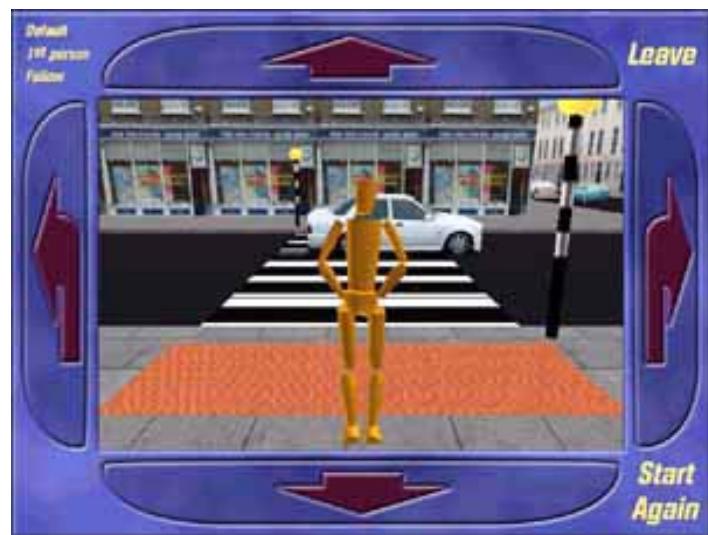


Figure 4. Virtual Zebra Crossing.

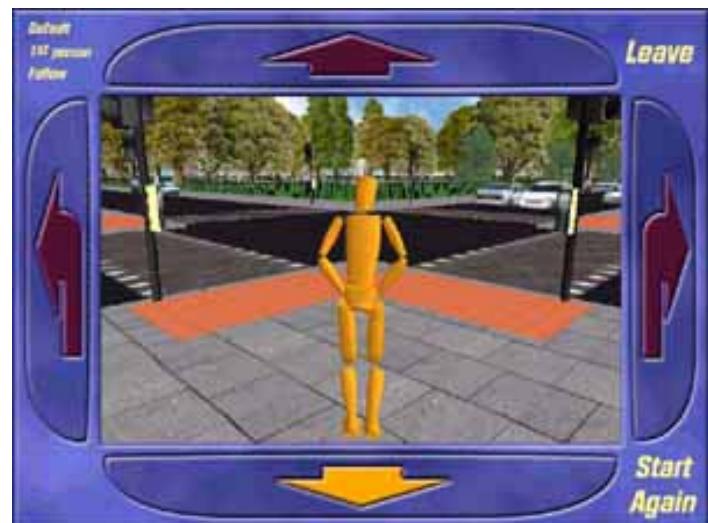


Figure 5. Pelican Crossing.

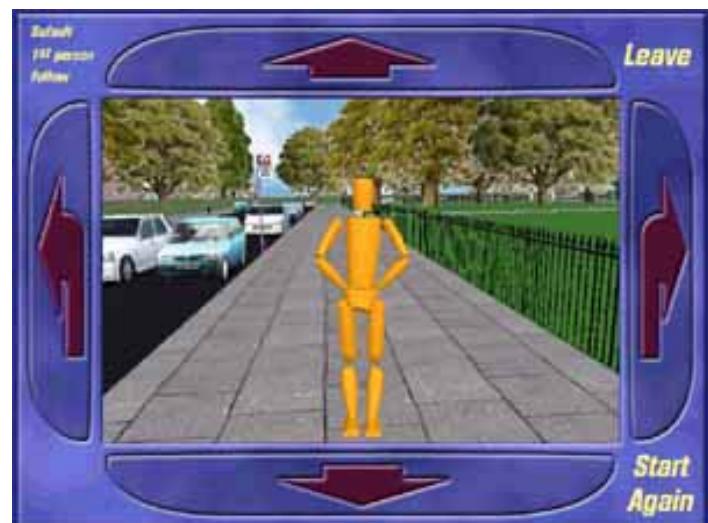


Figure 6. Route Finding.

#### 4.3 Tutorial three: Getting to the park

This tutorial aims to help the learner develop their own strategies, such as dealing with unexpected problems and route finding (Figure 6). It combines the previous two tutorials and also develops route finding skills by giving the learner an order from a simple map at beginning of the tutorial. The overall objective is to reach the park from a few blocks away independently.

## 5. EVALUATION

### 5.1 Overview

Of particular importance will be the evaluation of the transfer of skills from the virtual model to real world experience. Previous evaluation studies have shown that there is excellent transfer of virtually learnt skills to the real world in people with learning difficulties using the Virtual City (Brown, 1999). This type of study is, however, a long-term goal in this three-year project, and transferability will be determined in conjunction with researchers at Kings College, London. The results of such a study have potential implications for users in this project in terms of greater self-esteem, increased independent travel and greater access to work and training.

Before such a study takes place, two preliminary studies will occur. Study 1 is a case study with a small number of users to determine the usability of the system and Study 2 involves baseline assessment of the travel-training environment without embedded virtual tutoring agents. Reassessment of the environment after the design and implementation of such tutoring agents will allow their efficacy to be determined. Only preliminary results from Study 1 will be discussed in this paper. The members of the testing group for each of these studies will be drawn from a large day centre with over 200 residents situated within the London Borough of Sutton.

### 5.2 Procedure for Study 1

Traffic densities set at medium. Target set as invisible.

1. Zebra crossing, keyboard controlled – 2/3 repeats per tester
2. Pelican Crossing, keyboard controlled – 2/3 repeats per tester
3. Free wander in the park, joystick controlled – 1/2 minutes per tester
4. Zebra crossing, joystick controlled – 2/3 repeats per tester
5. Pelican crossing, keyboard controlled – 2/3 repeats per tester

## 6. RESULTS

The results from the case studies were as follows:

### 6.1 Case study results

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Name: A

Age: 40's

Gender: Female

No of encounters with package: 4 times of 10 minutes each. Total of 40 minutes of experience.

Observations

- Tendency to over steer when using the keyboard.
- Found use of mouse difficult (pressed both buttons).
- Attempted to press screen to activate Pelican.
- Joystick - slow start (actions too gentle), but rapidly improved performance as confidence grew.
- By end of session, voiced preference for joystick

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Name: B

Age: 40's

Gender: Male

No of encounters with package: 4 times of 5 minutes each. Total of 20 minutes of experience.

Notes: B has a severe tremor, making many manual tasks slow and clumsy.

Observations

- Found keyboard control very difficult.
- Using keyboard, completed Zebra with very little prompting.
- Found using the mouse/pressing a mouse button very difficult (pressed both buttons).
- Very quickly picked up control via joystick (with no known previous experience).
- Almost instant success using joystick on Zebra.
- Preferred viewpoint – 3<sup>rd</sup> person (avatar)

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Name: C

Age: 26

Gender: Male

No of encounters with package: 3 times of 10 minutes each. Total of 30 minutes of experience.

Observations

- Confused verbal queues of “left” and “right”.
- Confused verbal queues of “forward” and “back”.
- Keyboard tasks completed successfully.
- Did not really get to grips with the joystick – kept getting stuck going round in circles (see Additional Notes 6.2.)
- May not have been using his “best” hand.
- Preferred viewpoint – 3<sup>rd</sup> person (avatar).

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## 6.2 Additional Notes

The following additional observations were made on the experimental procedure:

1. Joysticks had not been presented to the users before; all previous encounters had been made using the arrow keys.
2. Joystick changed between B's first go and C's go, from long travel to shorter travel and more sensitive joystick. Both had difficulty with the 2<sup>nd</sup> joystick.
3. Training began one month before testing, most users having 1 session per week.
4. Usage very much tied to the first, basic tasks.
5. Trainer supported users with prompting and physical demonstration and assistance.
6. Trainer often asked users “Is it safe to cross the road?”
7. All users enjoyed the sounds associated with successfully completing a task.
8. Although mouse was difficult to use, the positive reinforcement associated with its use for pressing the WAIT button was felt to be useful by the trainers.

## 6.3 Technical Notes (possible interim modifications)

The following technical notes have been made regarding the performance of the travel-training environment during the experimental phase and are presented as possible interim modifications:

- Z-buffering of the pedestrian lights: red and green man are not always working. Important visual queues therefore disappear.

- Z-buffering of the textured pavement surface is also intermittent.
- Turning of the avatar is too sensitive. Straightening up can be a very difficult manoeuvre for many users. It may be possible to constrain the rotation to steps of 30 or 45 degrees (as an option).

## 7. FUTURE CONSIDERATIONS AND CONCLUSIONS

The aim of this project was to produce a flexible travel training environment to support constructivist training of people with learning disabilities. Results of an initial study and the reaction of trainers working directly with people with a learning disability have shown a promising degree of usability of the package. Later studies will evaluate the efficacy of embedded virtual tutoring agents within the package and the effectiveness of the package in terms of the transfer of skills into real world competencies.

Through analysis of results from the initial case study on usability, a number of design modifications are now suggested. Their implementation will improve the usability of the package and ultimately its effectiveness:

- Increase size of red and green men.
- Add User Records to allow users to preserve personal settings, facilitate data collection on performance and export (perhaps to .XLS) success and failure rates.
- Stop cars closer to the crossings, or widen the field of view, so that they are more visible from the stationary avatar.
- Add pedestrian islands.
- Add staggered islands.
- Add a subway (with multi-exit?)
- Add a footbridge.
- Add a wider range of road signage.
- Add buses with changeable livery, numbers (and destinations); single and double deckers.
- Add emergency vehicles.
- Disable joystick buttons.
- Scaffold interactions to a higher degree.
- Add an avatar of selectable gender: neuter (default), male and female options.

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# ICDVRAT 2002

## Session VIII. Acoustic Virtual Environments

Chair: Rachel McCrindle



# Sound-kinetic feedback for virtual therapeutic environments

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## ABSTRACT

This paper reports on the results of a pilot study on comparing auditory feedback to visual and kinesthetic only feedback as the more consistent feedback type that leads to developments in kinesthesia, motor planning, sequencing and timing capabilities. Development of kinesthesia, motor planning, sequencing and timing capabilities is tested through a learning and transfer of learning of a new unusual movement skill task. We defined as new unusual movement skill a target oriented movement performed under specific conditions that do not match real life movements. The participants were 28 learning deficient children 10-12 years of age randomly spread across 3 groups. There was the same number of participants across groups and gender balance within groups. All 3 groups went through two (2) Phases. In Phase I, Learning, the participant practiced the new movement across 8 trials using his/her not prevalent hand. In each trial the target was situated at different positions on the surface. In Phase I, each group performed in a different feedback Condition. In Condition A, the Visual Feedback Condition (VFC), Condition B, the Auditory Feedback Condition (AFC), Condition C, No Feedback Condition, (NFC1) In Phase II, Transfer of Learning, all three groups exercise the task with their prevalent hands in a No Feedback Condition(NFC2). The number of trials available was 4 so as training effects could be inhibited. The results showed that the VFC group performed notably better than the other two groups in Phase I (VFC: 95%, AFC: 15%, NFC: 12%). In Phase II, though, the AFC group performed better than the other two. These results indicate that auditory feedback seems to be a consistent feedback type leading to developments in kinesthesia, motor planning, sequencing and timing capabilities. Kinesthesia, motor planning, sequencing and timing capabilities are associated with mental processing and the development of mental structures on both a conscious and subconscious level developed in conditions where sound information is provided as feedback for movement. Even if the sound feedback ceases to exist the user can navigate his/her movement with the aid of these mental structures. The VE consists of a SGI Octane MXI system, a midi output, a digital camera and two laser pointers. The system was programmed in C and it creates an artificial environment that encodes the user's motion and can translate it into music in real time.

## 1. INTRODUCTION

According to modern neuropsychological studies (Baudbovy, Bridgeman, 1998), the practice of new kinetic dexterities is achieved through complicated cognitive processes of control and feedback (Willingham, 1998). According to the model of COBALT (Control - based learning theory), the usual kinetic dexterities are observed unprincipled from experiences of movements and their modeling base of kinesthesia, while in new type - extraordinary movements, where there is an observed disagreement between the objective of movement and the intellectual representation of her muscular activity, the practice is conscious and cognitively guided (Newell, 1991). Practiced in a dynamic, the new kinetic dexterity shapes a new model of movement depending on the precision of intellectual representation of his kinesthesia in this particular movement (Willingham, in press). Moreover, researches have shown that exists a positive cross-correlation between the musical perception and the kinetic record in a determined kinetic ordeal in the space (Rauscher, Shaw, Levine and Ky, 1994).

Previous researches in the region of sound-kinetik environments have shown the connection of musical perception with the visual perception. The originality of this research concerns those particular pieces of motor planning, sequencing and timing capabilities that has relation with the kinesthesia. More precisely it is our interest to show any relation between the development of kinesthesia, motor planning, sequencing and timing capabilities through a learning of a new unusual movement skill task accompanied with a musical perception.

Learning problems associated with memory and attention are seen in a wide range of diagnoses across the human lifespan. Most notably, attention difficulties are seen in persons with Attention Deficit Hyperactivity Disorders (ADHD), Traumatic Brain Injury (TBI), and as a feature of Autism. More effective assessment and rehabilitation tools are needed to address attention abilities for a variety of reasons. In children, attention skills are the necessary foundation for future educational activities. Accurate cognitive assessment is also vital for decision making regarding special educational placement concerns, the possible use of pharmacological treatments, and for treatment efficacy and outcome measurement. The conclusions of this study will be used for a better comprehension of mechanisms that is activated in motor planning, sequencing and timing capabilities inside sound-kinetik environments.

## 2. METHODOLOGY

### 2.1 Tools

- a) two computers with computational sound analysis software: Big - Eye (Steim) for the recognition of movement and 2) MAX - MSP for the production of sound,
- b) video camera for the digitalisation of movement,
- c) a mirror,
- d) surface of aiming - parallelogram leaf of Plexiglass, white colour.
- e) objective - ring of diameter 10 cm, from colourful cardboard.
- f) body of aiming - manufacture with piece of plastic pipe in the interior of which are 3 laser pointers, that gives common distinct trace in the surface of aiming. Externally exists switch of operation (on/off).
- g) sound system (amplifier and speakers)
- h) special glasses
- i) questionnaire on the control of Noeri's representation (MIQ)

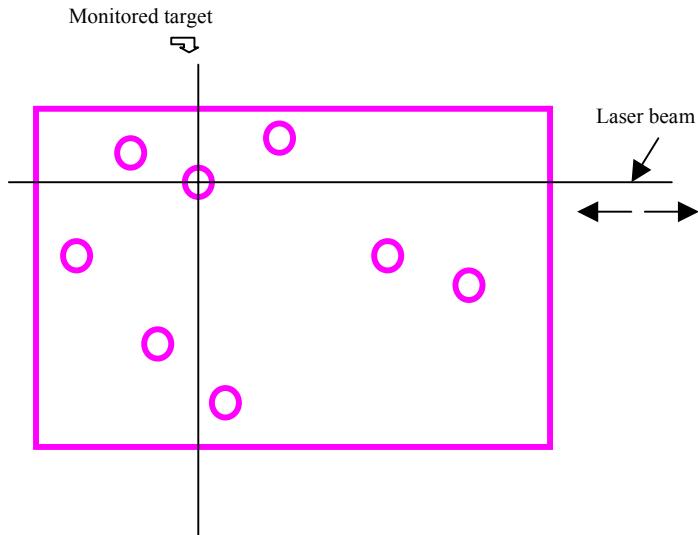
### 2.2 Description of the experimental environment

The experimental environment was shaped in a room of dimensions of 4 meters width and 3,5 length. In one wall was placed a mirror, in the opposite wall the surface of aiming and between them a chair turned to the mirror so that a person seated in the chair sees from the mirror the surface of aiming behind him. A video camera was placed next to the chair turned to the surface of aiming and a pair of speakers at both sides mirror. In the floor near in the chair was placed a pedal that would be controlled from the leg of the seated in the chair. The surface of aiming (smaller than the wall) was delimited with film of different colour from the wall.

When we a beam of laser is activated and we aim with this in the surface of aiming, information of movement, from the trace of the beam laser, it is transmitted in the computer with which the camera is connected. Then this information is transported in a second computer where it activates the production of sound that follows in real time the movement. The process of information transmitting and movement encoding can be seen at the figure 1.

### 2.3 Sample

The choice of sample became with accidental sampling from the region of Thessalonica. The attendance was voluntary. The sample of pilot research is constituted by 28 learning deficient children of age of 10-12 years and was shared in 3 teams (Visual Feedback Condition, Auditory Feedback Condition and No Feedback Condition) of 10 individuals.



**Figure 1.** The sound-kinetic environment was created in real time in 2D space. Any movement that is performed from the subjects is converted into sound.

### 3. PROCEDURE

The participants arrived individually in the place of the experiment, where they were given specialized directives depending on their team. They practiced a supplemented questionnaire on the control of mental representation (MIQ) in Greek and then they were sited in the forecasted place, in front of the mirror so that they can check optically the space where they will be presented with the objective. Using the non-dominant hand in the same shoulder, they tried to aim. In the leg there existed a pedal-switch, which they could step whenever they consider that they achieved the objective, in order to stop the effort. The experimental process was completed in two phases. In the 1st phase of the experiment all the three teams took part, as a stage of the actual practice. In the 2nd phase of experiment the three teams took part, realizing the kinetic ordeal with the dominant hand, as a stage of transfer of learning.

#### 3.1 Phase I

The efforts in the first phase are 4 measurable and two test, for each subject of teams (A), (V) and (G).

**3.1.1 Team A (VFC).** The feedback that helps the subjects of team (A) to direct the movement of their hand (not dominant) it will be exclusively optics that is to say, the subjects will see, the trace of the luminous beam above in the surface of projection in the place of the objectives, without no sound stimulus that could guide them through.

**3.1.2 Team B (AFC).** The feedback that will help the team (B) in order to they direct the luminous beam with their hand (not dominant), was exclusively sound. The participants could not see the trace of the luminous beam that they directed above in the surface of projection. We used glasses with chromatic filters that prevented the view of the luminous trace, while they aimed at the target. The sound signal that is shaped depending on the relation of luminous beam and objective, constitutes the only source of information (for the subject) and for the result of the movement.

**3.1.3 Team C (NFC).** The participants of the third team (C) would try to direct the movement of their hand (not dominant) without feedback, guided only from their conscious kinesthesia perception for the place of their hand (arm - shoulder) and the intellectual representation of direction in which the luminous beam would hit the visible objective.

#### 3.2 Phase II

In the 2nd phase all the three teams are executing precisely the same procedure, but with the dominant hand and with just 2 trials. Participants are called to aim as good as possible better, and to declare the achievement of the target with the step of pedal in the flooring.

## 4. RESULTS

The results were connected with the answers in the questionnaire on the control of mental representation (MIQ) via qualitative analysis. In the phase of the actual practice the results showed statistically important differences in the yield practised ( $F(df=1)=8,024, p < 0,05$ ). In the phase of transfer of learning with regard to the distance by the objective, and the time of completion, were not presented statistically important differences.

With regard to the absolute success for the objective, an analysis of fluctuation of direction was used in order to examine the differences between the three teams (sound, optics, locus of control) in the phase of the actual practice and in the phase of transfer of learning. The results showed that there existed a statistically important difference in the actual practice ( $F(df=2)=66,309, p < 0,0001$ ) in favor of the audio team and in the transfer of learning ( $F(df=2)=1,009, p > 0,05$ ). The no feedback team ( $M=1,7975, SD=2,144$ ) had evidently better performance than the visual team ( $M=0,862, SD=0,611$ ), but was not however statistically important. The better "performer" was the sound team with a 100% of successes "4" (four efforts), which achieved a mean 0,4636 ( $SD=0,889$ ). Second, with null difference were the team of no feedback control ( $M=0,4578, SD=0,1180$ ) and last optical team (0,1180,  $SD=0,315$ ).

## 5. CONCLUSION

The occurrence of pure attention vs. pure hyperactive vs. mixed subtypes may be better assessed in a Artificial Environment where, in addition to cognitive performance, motor activity levels can be recorded via the position tracking system. This might also be of particular value for assessing the effects of medications on performance. While pharmacological treatment may produce a measurable decline in motor "fidgetiness", it may be found through measurement within a Artificial Environment, that concurrent attention does not improve. This may also be of value for examining gender differences in the diagnosis of this disorder since the male predominance reported in incidence statistics have ranged from between 4:1 and 9:1 depending on the setting where the data was collected. Perhaps boys are more commonly diagnosed due partly to differences in occurrence of the more "observable" hyperactive component. By contrast, girls who do not manifest the hyperactive component may be less "noticed" yet may still have attention deficits that go undiagnosed.

The special young experience cognitive/functional impairments due to various developmental and learning disabilities. Estimates place the number of children receiving special education services at between 2.5 to 4 million (estimated from CORDIS database, 1999). Rates of other childhood learning disorders, such as Attention Deficit Hyperactivity Disorder (ADHD) and reading disorders, push estimates even higher. Methodological complications preclude precise estimates of the cost of ADHD to society, but according to 1995 statistics, additional national public school costs for these students may have exceeded 3 billion Euros.

The cognitive process of attention is well suited for a comprehensive Sonic Movement assessment and rehabilitation approach. Within the SM environment, the interactivity between sound and movement was realized through one camera and two computers using the BigEye (Steim) for movement recognition and MAX-Msp for sound production. Current methods for assessing attention difficulties include traditional paper and pencil tests, motor reaction time tasks in response to various signalling stimuli, flatscreen computer delivered approaches, and behavioral observation techniques. These methods have limitations regarding issues of reliability and validity, and behavioral observation methods are additionally time consuming and costly. Rehabilitation approaches for this cognitive process also suffer similar obstacles.

Students with severe learning difficulties can use experiential learning programs to access a rich set of environments, both in terms of objects and situations, to interact with them in appropriate contexts and in ways they are restricted from doing so in the real world. Similarly, learning experiences can be structured for children with learning difficulties to break down complex tasks into more simple components until the child masters the necessary skills. Another advantage of SM described by Wilson, Foreman & Stanton is that the need for semantics, symbols or language is virtually eliminated, due to the experiential nature of the learning process. This means that SM is more accessible to different categories of users who may benefit from learning a task in SM without the restrictions of traditional teaching methods.

It is this freedom of exploration and expression which may go some way in restoring the disparity that exists in real world learning systems; to give easy and frequent access to environments that are not so in the

real world, and to accommodate experiential ways of learning rather than concentration on the abstract learning systems that prevail in mainstream education.

The superiority of SM as compared to traditional educational tools is based on rather well-understood factors such as physical and psychological involvement – known as “presence” – free interaction, and buildup 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 at overcoming 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, etc. The SM system will utilize interface technology that renders computer information onto multiple human sensory systems to give a sustained perceptual effect (i.e., a sensation with a context). Perception and expression of greater quantities of complex information will be the end value to expert knowledge users.

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# VirtualAurea: perception through spatialized sound

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## ABSTRACT

Blind children cognition is currently enhanced by using tactile-based methods such as the Braille system. The use of sound for cognitive purposes is not common in the blind educational community. Even though these facts, an increasingly number of studies are showing that blind children can develop cognitive structures through the interaction with spatial sound. Most studies use specific purpose software to help blind children to construct cognition and learning. A common characteristic of these studies is the absence of robust usability studies that inform of the adequacy and user satisfaction with this sound-based software. This paper introduces VirtualAurea, a flexible software editor for sound-based virtual environments designed “with” and “for” blind children to construct their cognition. It also presents a complete usability study to validate the editor with blind learners by using a kit of cognitive tasks. We also determined the impact of the interaction with this software editor on the development of basic cognitive functions, operations, auditory perception, laterality, comprehensive language, and tempo-spatial orientation mental skills of blind learners.

## 1. INTRODUCTION

A number of recent studies indicate that spatial structures can be developed and used by blind children through the interaction with virtual worlds through audio interfaces (Baldis, 2001; Lumbrales & Sánchez, 1998; McCrindle & Symons, 2000; Mereu & Kazman, 1996; Sánchez, 2000a, 200b, 2001; Sánchez & Lumbrales, 1999; Stifelman, Arons & Schmandt, 2001; Sjostrom, 2001; Tan, 200; Winberg & Hellstrom, 2000). Most of them are pilot studies with major emphasis on the development of computer applications rather than focused on blind user-centered design with fully usability testing to tailor virtual environments according to the interest, needs, and mental models of blind children.

In addition, most of these published applications are specific purpose software with limited flexibility to allow teachers, parents and the child to modify the structure and functionality of the software. There is no way that control, complexity, versatility, and flexibility can be determined by both software designer and end users.

Lumbrales & Sánchez (1998, 1999) developed a pioneer application that allows blind children to navigate and interact in a virtual world based on modeling the computer game Doom by using spatial sound interfaces. In this pilot study the researchers proved the potentiality of the exclusive use of audio to represent basic spatial cognitive structures depicted by main and secondary corridors. The navigation through sound-based virtual worlds triggered mental models of the spatial representations very close to the structure embedded in the software. A group of seven learners ages 8 to 11 experimented with the software during two months and attained concrete representations of the navigated virtual space including objects and entities through the use of Lego bricks. Authors concluded that it is possible to use spatial sound to stimulate blind learners to construct navigated spaces in an interactive virtual world. This initial experiment also informed about input and output interfaces concluding that devices such as the keyboard and ultrasonic joysticks adjust to the requirements of the blind children as well as external speakers instead of earphones.

This seminal study was the starting point of an entire research line about spatial sound and cognition in blind children. Even though the initial results were promissory a number of questions arose from this study. As a result, Sánchez & Lumbrales (2000) developed a full field study designed with a kit of cognitive tasks

and a careful research planning by using the same sound-based computer application named AudioDoom (Sánchez & Lumbrales, 1998, 1999). They added a strong component of task concrete materials to support the representation of navigated spaces. The kit of cognitive tasks consisted of a set of learning activities with objectives and specific actions. This allowed focusing the research on the development of specific spatial skills. After working four months with forty blind children and following the stages of: 1. Interacting with AudioDoom, 2. Representing the navigated virtual environment, and 3. Constructing the models with sand tables, Styrofoam, Lego bricks, sand, clay, and corporal exercises, authors concluded that there are four levels of children's cognitive attainment when interacting with spatial sound virtual environment: Entry, Exploration, Adaptation, and Appropriation. These levels imply an increasing cognitive complexity to model the cognitive tasks. Adaptation and appropriation are the highest level of spatial representation and mental modeling after using sound-based software and perform cognitive tasks. The whole research concluded by stating the viability of assisting the construction of mental structures through the use of spatial sound with a set of cognitive tasks. The sound *per se* does not have an impact or "effect" on the development of spatial cognitive structures. The cognitive tasks with didactic implementations are critical to obtain the expected results. The study also concluded that spatial mental images could be constructed with spatial sound and without visual cues. Images can be transferred through spatial sound that emerges from interactive virtual environments.

One of original sides of this second study was the comparison made between the behavior of blind and sighted children when navigating the same audio-based virtual environment and solving cognitive tasks with concrete materials to represent the environment. As a result, sighted children reached only the exploration level and blind learners attained the highest level of cognitive appropriation. This implies that sighted children do not base their cognition in the aural perception, they heavily rely on the visual perception. Learning through sound is very poor in sighted children and perhaps these results can shed some lights to better stimulate cognition through the use of sound.

Diverse research lines emerge from this study. Perhaps the most direct is the necessity to have more versatile, flexible, and complete sound-based software to allow modifying the navigating scenario and the possibility to go back and shift in the software map. This called for a software environment that allows a wide diversity of cognitive tasks based on the work with the spatial sound elicited from the interaction with the computer. The possibility that the teacher or parent of the blind children can design software upon the framework of a generic editor was a challenge for the research.

The related literature present diverse experiences with auditory stimuli to mimic visual cues for blind children. Mereu & Kazman (1996) found that the use of 3D audio interfaces by a blind person could help to localize a certain point in the 3D space. This was performed in such a precise way as with a sighted person interacting with a graphical interface, even though it took more time for the blind person. They also found that in environments exclusively based on sound users with visual disabilities were more precise than sighted users.

Cooper & Taylor (1998) highlights the effect of 3D sound interfaces in virtual environments and applications for blind people. Lahav & Mioduser (2000) successfully developed a study on the premise that providing appropriate spatial information through compensatory channels can contribute to the spatial performance of blind people. They developed a multisensory virtual environment with the support of force feedback joysticks simulating real life spaces such as the school, the work and public buildings. Winberg & Hellstrom (2000) developed an audio version of the game Towers of Hanoi. The idea was to investigate the nature of the persistent presentation and what it may mean when implementing audio direct manipulation. The results showed that it was possible to implement audio direct manipulation by using the Towers of Hanoi as a model as well as the fact that having a set of objects, the nature of the continue presentation was not relevant as the interaction with the audio space.

McCindle & Symons (2000) implemented a study in the same context of AudioDoom (Sánchez & Lumbrales, 1998, 1999) in order to probe that the standard characteristics of a traditional game such as Space Invader can be replicated by using audio 3D by using force feedback joysticks as input interfaces. They concluded that it is possible to produce a multimodal game played by blind and sighted people providing them a way to share the same game experience.

Baldis (2001) conducted an experiment to determine the effect of spatial audio on memory and perceived comprehension of conferences with nine participants, concluding that spatial audio improved memory and perceived comprehension and that participant preferred spatial audio instead of non-spatial audio. Stifelman, Arons and Schmandt (2001) developed AudioNotebook a tool that augments the user's activity by helping to

find desired portions of audio. AudioNotebook is a device for taking notes and interacting with a speech recording as a new approach for navigation in the audio domain. This allows to free listeners to devote more attention to the talker, so they are not always required to take notes.

Loomis, Lippa, Klatzky & Golledge (2002) designed a study with blind and blindfolded sighted observers presenting them auditory stimuli specifying target locations by using 3D sound. They assessed the ability to mentally keep track of the target location without concurrent perceptual information about it (spatial updating), concluding that once an internal representation of a location has been determined, posterior-updating performance is independent of the representation mode.

Most of these studies called for a full usability study. Our experience with these sound-based computer applications has taught us that to map blind people mental models can only be possible if we test and retest with them the software and devices we built for them. This is the persistent paradox of developing software for blind children by sighted adults. Mapping the mental model of a child is a difficult task, mapping the mental models of blind children is more complex and an unexplored matter.

Our research team has explored spatial cognition but complex areas and spatial conflicts have been less explored with the use of sound. There is also a need for implementing tasks to stimulate tempo mental structures as well as working with small children to early support them in the development of tempo-spatial. This will help to level them constructively with the same cognitive knapsack of sighted children to face their intellectual development with similar conditions even though they can not decode visual stimuli that is embedded the surrounded cognition. Our study intends to consider some of these concepts.

The purpose of this study was to design and implement VirtualAurea and then to determine the impact on the development of basic cognitive functions, operations, and tempo-spatial skills of blind learners using interactive sound-based computer tools. We investigated a way to develop through the interaction with audio-based software editors, auditory perception (memory, consciousness, discrimination), laterality (concept of left and right with respect to the own body), comprehensive language and tempo-spatial orientation (front-back, between, alongside, before-after, slow-rapid).

## 2. RESEARCH MATERIALS AND METHODS

### 2.1 Materials

To implement the testing we used the following materials: four PCs Pentium III with quadraphonic cards and four speakers, VirtualAurea, colored geometric pictures with different sizes, sketches with the graphical representation of the software map, musical instruments (tambourine, pegs, Indian reed flute, oboe, guitars, etc.), panel boards to physically represent the walls and corridors of the software, and a digital camera.

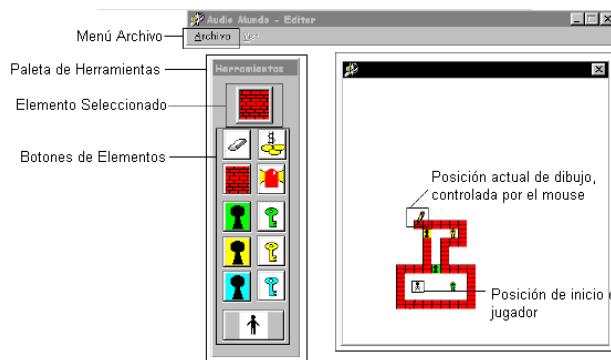
### 2.2 Software

VirtualAurea is a software editor to navigate custom-made spatial structures through spatial sound. It is a flexible tool to create virtual scenarios. It allows children to perform diverse movements and opens the possibility to flexible place objects throughout the scenario. This allows having a better management of the level of difficulty of the tasks, allowing the creation of maps or spatial structures adequate to the cognitive level of the learner. The option to change constantly the scenarios allows keeping attention alive and the motivation of the child. VirtualAurea allows a high degree of freedom in the movements with a more intuitive and real simulation of the environment.

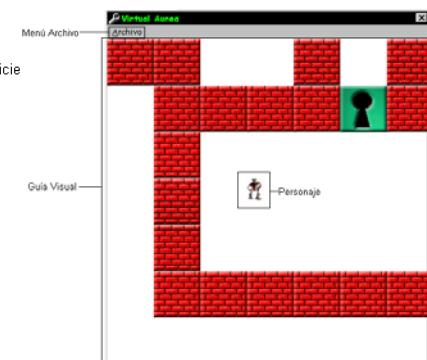
VirtualAurea was built upon a PC platform, operative system MS Windows 95, C++ and programming environment Visual C++ 5.0, using a libraries of Microsoft DirectX 5.0 multimedia routines. VirtualAurea is conformed of two independent programs: An editor that generates the files that define the maps, create, save and modify maps, and the game or software that opens the maps generating the visual and auditory representations. The editor has an interface and draw tool as displayed in Figures 1 and 2.

The editor gives total freedom to the user to create maps without limitations to displace elements. This allows that a map can be saved, modified or played anytime the user wants. The game mode interface is simple because the main information source for the blind child is delivered through auditory channels.

To move in the game we use three keystrokes: left shift ( $45^\circ$  upon its own axis), right shift ( $45^\circ$  upon its own axis) and to move forward. Due to the fact that in any standard keyboard the keystrokes "f" and "j" are marked with small dots, we chose the keystrokes "f", "j", and "k" to shift left, right and move forward.



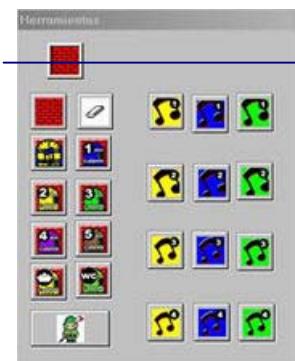
**Figure 1.** Graphic interface of *VirtualAurea*.



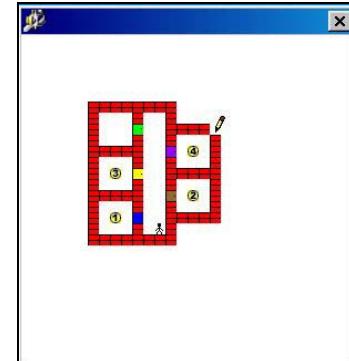
**Figure 2.** Graphic interface of one game generated by *VirtualAurea*.

*VirtualAurea* is a generic platform upon which we can construct specific applications. For this study we built an application called “The Music Castle”. The idea behind the software is that while the child picks pieces of a song in the correct order s/he can get higher score and can be able to listen to the song. The level of difficulty can vary when different pieces of diverse songs are introduced. In such a case the child should be able to discriminate what pieces correspond to the song that is looking for. To work the notions of spatiality each object in the map emits a sound that is placed in a determined position and location within the auditory spectrum. Thus the child can exercise concepts by searching objects that are to the left, right, front or back, according to the location of the sound emitted. The notions of temporality are exercised through the recognition of the corresponding position of a musical piece. This allows to reinforce concepts such as position (first, second, third, fourth) and numbers (one, two, three, four).

The Music Castle is based on *VirtualAurea* then it is conformed of two modes: the editor of structures and the game that reproduces auditory and visually the structures generated by the editor. The editor (see figures 3 & 4) is a program that allows creating diverse structures of The Music Castle by the teacher.



**Figure 3.** Graphic interface.



**Figure 4.** Draw area.

The main goal of The Musical Castle is to help children to identify the corresponding pieces of a song. To do this they have to recognize the object’s sound placed in the navigating spatial structure and identify the position. Once the children find a piece of the song the melody is listened and they choose a fragment of the song. While they use this application the teacher guides their performance by reinforcing the concepts of laterality, temporality and language.

To get a spatial position the game emits sounds coming from different positions of the space. For example, if an object is behind the subject controlled by children, the sound comes from the back speakers as it is placed in the back. If the object is placed to the left the sounds come from the speakers that are placed to the left of the child. To move toward an object the children have to shift until they perceive the sound of the object as it comes from the front through the front speakers. Once the child places the subject in this way he later can move toward the object with an intention in mind.

### 2.3 Methods

The study was held during the year 2001 in a Chilean school for blind children. The school is conformed of children that are totally blind and others with residual vision. A multidisciplinary team of professionals assists these children. The school has enough infrastructures to lodge learners in a Monday to Friday internship system. Children come from economically poor and socially deprived families. The research was implemented in the computer laboratory.

The research was implemented during six months with nine children with visual deficits ages 6 to 12, seven boys and two girls. Seven children have residual vision and two were totally blind. Three of them have also diverse intellectual deficits, four have slow mental performance and two were tested intellectually normal. Each week they worked during three sessions of 30 minutes with VirtualAurea and 25 minutes solving cognitive tasks

We used an intact sample of 12 learners, three of them left during the study for family problems. Then we systematically worked with nine cases. These children were evaluated each year by a multidisciplinary team. They evaluated both the visual capacity and IQ by using the standardized test Wisc- r, Wechsler reviewed scale for blind children. Using a national test battery for verbal exploration, BEVTA to evaluate psycholinguistic processes. We also used two specific tests of this battery, TAVI and 3-S. TAVI evaluates the auditory receptive of the oral language, immediate verbal reception, oral comprehension of simple paragraphs, short time attention to verbal stimuli and verbalism of a answer. 3-S evaluates verbal abstraction, sameness relationships and vocabulary recognition.

We used this test because language structure is related not only with temporal sequences in a grammatical structure of a phrase, rather it also involves abstract thought and the capacity to understand directions. The interactive virtual environment used in this study has a great deal of information given in oral language that has to be comprehended and structured coherently.

The progress of children was evaluated through the use of cognitive tasks. We developed three tasks to work with VirtualAurea. They were designed to help children to 1. Integrate tempo-spatial references perceived as sequential realities, 2. Demonstrate the construction of knowledge about the virtual space of the software, and 3. Evidence the knowledge/mapping of the virtual space. The idea with this kit was to provide a tool to the mediator to assist the use of VirtualAurea by blind children. It also provides diverse activities to complement the use of VirtualAurea. Finally, it is a way to exercise tempo-spatial skills necessary for reading and writing and pre-cane techniques.

In addition, besides to cognitive tasks and tests, we documented our results by using diverse methods such as checklists, anecdotal notes, interview, recording, filming, and taking digital photographs.

## 3. RESULTS

Our main results can be analized around the cognitive tasks designed.

**Cognitive task 1. To relate tempo/spatial concepts and the mapping of the sound-based virtual space.** Blind learners integrated tempo-spatial concepts and mapped the virtual space through the interaction with the game by solving progressive complex tasks to put in order elements of the software. Thus they progressively attained the exploration stage. All of them attained the goal for this task. They interacted with VirtualAurea very easily (see Figures 5, 6, 7, 8 and 9).

**Cognitive task 2. To evaluate temporal concepts related to the rythm in the performance of actions (fast/slow).** Learners were able to evidence progress in their movements, orienting through acoustic stimuli. This requires a certain level of concentration on the activity. They can discriminate rhythm and sound in different velocities and reached the level of adaptation. They again represented very precisely the structure of the virtual environment (see Figure 10).

**Cognitive task 3. To develop laterality and spatial concepts.** They had to recognize their ownn space to orient themselves and demonstrate the spatial knowledge of VirtualAurea. Learners recognize the space for orientation and demonstrate the spatial knowledge of the program. They applied tasks related to tempo-spatial notions by using their bodies and moving physically through the represented environment. They not only can interact with the virtual environment but can also move through the real environment that

VirtualAurea represented. They are able to relate doors with the music instrument that represent them and also to order in a chronological time as they appear in the software (see Figures 11 and 12).

### 3.1 A sequence of the experience illustrated with pictures



**Figure 5.** The learner interacts with the game receiving information through the four speakers.



**Figure 6.** The learner develops the Concept of chronological ordering.



**Figure 7.** The learner orders puppets and dolls representing the chronological time.



**Figure 8.** The learner orders concrete elements in a board.



**Figure 9.** The learner orders illustrations in a chronologically.



**Figure 10.** The learner works in a sketch of the virtual environment reflecting the mental image of the structure.



**Figure 11.** The learner performs laterality tasks.



**Figure 12.** The learner performs spatial tasks by using his own body.

#### 4. DISCUSSION

The main goal of this study was to determine the impact on the development of basic cognitive functions, operations, and tempo-spatial skills of blind learners, of using interactive sound-based computer tools. Our results evidence that sound not only supports the child's development of spatial representation skills as in past studies already discussed but also facilitates the development of basic cognitive functions and temporal skills. This extends the scope of cognitive processes that can be improved with adequate use of sound-based virtual environments.

Qualitative and quantitative results indicate that when we use VirtualAurea + spatialized sound interfaces + cased-based cognitive methodology including tasks and tests to measure space and time representations of navigated virtual worlds, blind learners can develop tempo-spatial cognitive structures, diversify and make a deeper development by transferring them to everyday tasks. Spatial sound delivered through the interaction with computers by navigating and interacting with objects and virtual world entities can be a powerful medium to represent information and knowledge by blind learners. This can be critical with early learners with urgent needs to minimize access deficit that separate and divide them from the cognitive experiences of sighted learners. Once more we highlight the potentiality of sound as powerful tool to enhance learning and cognition in blind children.

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# Interaction with shapes and sounds as a therapy for special needs and rehabilitation

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## ABSTRACT

Causal interactive audio and visual feedback sourced from whatever faculty is available from children with severe disability and utilised within an adaptable user-friendly interactive environment that encourages, motivates, and is “fun” to participate within has proved to be a rich resource within which to research towards possibilities for the children to reach their fullest potential. This paper details the practical implementation of further (related to earlier work) various visual media; virtual reality; and associated technologies so as to further enhance the study and to verify the feasibility towards a commercial system product.

## 1. INTRODUCTION

### 1.1 Who and what?

The authors were previously involved in earlier research projects within the special needs field. One was a recent EU funded project that solely focused on the sonic aspects of interacting with sensor appliances to children of various ability and disability; another project has a longer history of researching applications of synchronous audio and visual interactions within adaptive interactive multimedia environments as applied in special needs and rehabilitation. These two projects are subsequently referenced as background below.

Our paper reports on the use, within the field of special needs and rehabilitation, of interactive feedback in the form of Virtual Reality objects, shapes, and sounds to encourage movement. The approach centers upon a novel concept/observation termed ‘aesthetic resonance’ - referring to a situation where the response to an intent is so immediate and aesthetically pleasing as to make one forget the physical movement (and often effort) involved in the conveying of the intention. In the past, such repetitive movements/exercises have been either tedious (in the rehabilitation field) or indeed impossible to achieve by previous means (in the special needs field with severely handicapped children). The potential for such a system, concept and methodology which is able to adapt to an individual user profile, in all aspects, is shown to be of great value for further academic research, commercial opportunities, and more importantly, the opportunity for an improvement in quality of life possibilities, applications in new therapy, and usage as a supplementary aid towards general well being for the participants. These potentials are further explored in our segued EU funded IST project titled CARE HERE. Results confirming the potential of this fresh approach are given.

### 1.2 Background – Sound (EU CARES Project) – Sound/Visuals (HANDI-MIDI/SOUNDSCAPES)

Some severely handicapped children are denied to a large extent the experience of movement. This includes a denial of all that follows from this including the ability to approach, reach out, discover, manipulate and

make sense of the world around us. The world of sound, fortunately, is as accessible and available to these children as to anyone else, which enabled the EU CARESS (Creating Aesthetically Resonant EnvironmentS in Sound) Project to explore the enjoyment and benefits those children can derive from immersion in a *sonic* environment. The authors<sup>3,4</sup> were key researchers in the CARESS project and a reference to this work can be accessed through the web site <http://www.bris.ac.uk/caress>

One of the authors<sup>1</sup> established HANDI-MIDI/Soundscapes in 1987 – (initially titled HANDI-MIDI, later changing and referred hereafter as Soundscapes) – as a self-funded research and development project originating from experiences and interactions with family members with a disability. The concepts and methodologies of utilising multimedia, within his self termed Virtual Interactive Space (Brooks, A. L. 1999) as an interactive play environment to aid in quality of life, therapy and other ‘special needs’ issues developed through years of sessions in which he palpably witnessed the influencing effect that was possible within his applied ‘user-created’ interactive audio visual environments. The work has been termed as an aid to augmented and alternative communication. The desire for optimising the potential for participants’ experiences within the environments, as well as the creation of a system that could satisfy the prerequisites, drove the project to its current status as a continuing pioneering and open structured innovation.

### *1.3 Foreground – Virtual Reality (EU TWI-AYSI probe)*

The European organization i3net funded future probe Twi-aysi (The World Is – As You See It) emerged from the CARESS Project to answer the question:

Can immersion in a *visual* environment hold similar potential for such children in terms of the aesthetic resonance they might derive from *movement* within such a visual space?

Our paper reports on the technical approach and results achieved in answering this question and the fresh applications that have arisen out of its successful completion. It details our technical approach, the experiments we conducted, and the results achieved from the various multimedia environments. The evidence of technical soundness and relevance of results is supported by the photos and on-line video mentioned in the appendix.

## **2. EQUIPMENT, TECHNICAL APPROACH AND METHODOLOGY**

### *2.1 Equipment*

The Soundscapes system was used in Twi-aysi. Soundscapes refers to a concept and methodology. However, when referenced as a system, it refers to a conglomeration of equipment, assembled according to the authors’ prerequisites from prior experiences which, when incorporated as a whole, is capable of capturing body function data information (for example, movement data, breath pressure, biofeedback) which can then be used as a source for real-time interactive manipulation and control with multimedia. The capturing of the body function data information can be sourced from a selection (or a combination) from a variety of equipment: for example, sensors, cameras, biofeedback and other peripherals.

The most often chosen capture device utilised in Soundscapes has been infrared beams where movement within a single or multiple pseudo 3 dimensional area(s) which is emitted in the form of an ‘egg shaped’ infrared beam of light can capture data. The sensitivity of the areas can be easily programmed according to each individual participant. The range of the Virtual Interactive Space can be selected and created according to the desires of the participants from a mere few centimetres up to around fifteen meters by using high reflection panels. In this way small body part movements, such as a finger twitch, or full body movement, such as a standing balance rotation exercise, can be sourced for processing to affect the selected multimedia feedback.

Available visual feedback depends on the software and hardware configuration of the system. Music programs are readily available that accept the system protocol signal of MIDI. “Video Jockey” programs are becoming increasingly available; they enable a selection of triggering a basic assigned image to more sophisticated programs that enable real-time manipulation of an image – even three dimensional images & environments. The ability for the program to enable the user/therapist/family member to select images and to even scan in photographs that are personal is a prerequisite. Sound output from the Music program can also be used as an input to the readily available visualization programs via the line input to the computer. In the sessions in both Sweden and Denmark we used a basic paint program that accepted MIDI.

## 2.2 Technical approach

For the Twi-aysi sessions it was decided to begin with synchronized digital sounds with digital colouring of image sequences through mapped gestural data sourced from users movements within single and multiple infrared beams. In the Swedish sessions, a retail product called Dbeam by Interactive Light from Santa Monica, USA was utilised. This is an infrared sensor box with the above attributes. In the Danish sessions however, two prototype sensor boxes were used. The first prototype was created, designed and constructed by the author (1). The second prototype was an adaptation from three Dbeams to the authors' design assembled into a 19" rack flight case. Both prototypes consist of a three-headed infrared sensor array with each having the emitter and receiver mounted at the end of an easy flex miniature gooseneck. This was to enable minimum intervention and ease of set-up and adjustment of the interactive areas. Both prototypes are capable of capturing the movement data information that is assigned, via an easy user interface, to similar or different channels of operation within the MIDI protocol. The three channels can each be selected to transmit on either channel 1, 2, 3,...or 16, and a choice of data information can be selected (for example; note on, control change, pitch bend etc.). The range of the data information can be programmed to suit the user profile of the individual participant. The three signals are collected into one output cable to be further routed downstream to a computer via a MIDI interface.

## 2.3 Methodology

The collaboration between the prime researchers provided a wealth of experience within which to explore the application of visual media, solely beyond the sonic, within the field of special needs and specifically, with the children with severe disability. Both researchers have many years of experience with these and other similar children. To make the children comfortable, previous tried and tested technologies, user preferences (where known and applicable), and user limitations were integrated and initiated at both test locations. Thereafter, new explorations with the available technologies were selected for the user to experience such that an immersive visual experience was created to encourage the desired expression through movement that would give an indication of an aesthetic resonant achievement.

Evaluation was through Multiple Camera Analysis (MCA – Brooks, A.L. 1999) technique that entails two or more cameras set up so as to capture various views of the interaction. These cameras can matrix feed between: monitors and a switch box for live monitoring and switching, separate videocassette recorders, or directly into a video capture facility on the computer. The archived videos are synchronized so as to enable multiple view analysis for observation of all qualitative movement and other signs from the session that may be an aid towards a quantitative evaluation. MCA also enables options for camera angle switching selection in post session presentations.

## 3. DESCRIPTION AND RESULTS

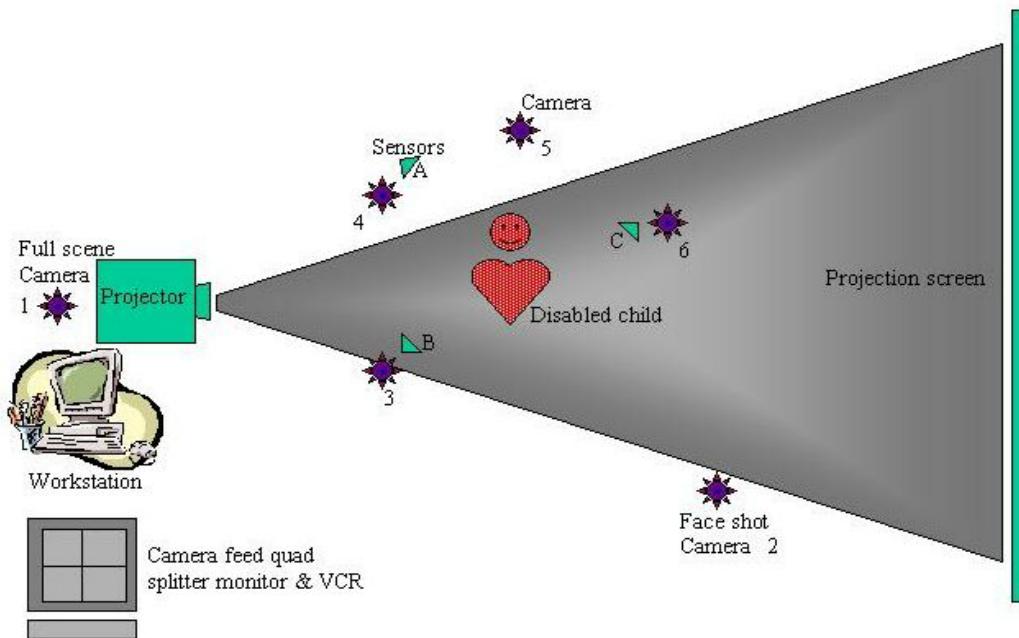
### 3.1 Sessions description - Sweden

The sessions in the special needs school in Landskrona were with eight children of mixed gender and various ages between six and seventeen, with various levels of disability. The sensor space was created with three separate sensor heads as detailed above assigned to MIDI channels 1, 2, and 3 on the hardware interface display. The signals fed a 3 to 1 merge box and subsequently the output was fed into a computer running Opcode Max. The simple patch in Max allowed the mapping of the gesture data information to a MIDI input paint program and to be output externally to a MIDI sound module and MIDI sound effect unit.

Due to delays in setting up on the first day and the user falling asleep, the sounds and images were preset before the user entered. The sensors (A, B, C) were mapped externally to 1, 2, or 3 different patches/instruments in the sound module and effect combination, and internally to the paint program to colour filters in the colour synthesizer window. This affected the Red, Green and Blue parameters so as to open the colours to input to the (black driven) sequence created by the author prior to the session. Various real-time changes were undertaken within the sessions depending on user reaction. These changes ranged from mapping all three channels to a single channel and thus instrument patch and colour, to extreme visual interactive causal sensitivity swings (varying the amount the movement caused the response).

Six cameras (1 – 6) were implemented so as to archive the sessions. Four of these cameras, which were each focused on the various expected interactive body parts fed a quad splitter and subsequently, a videocassette recorder. One camera was set up so as to record close facial expressions and another was set up

to record the whole scene. A workstation set up controlled all parameters of the session downstream of the programmed sensors.



**Figure 1.** Camera/sensor set up.

### 3.2 Sessions description - Denmark

The sessions in Denmark were with four male children with severe disability ranging in age from three to five years of age. The sessions began with three days in the Experimentarium, a large empty space, and then two days in the Panorama Virtual Reality room; both are located within the Center for Advanced Visualisation and Interactivity in Aarhus. MCA was again used with two cameras set up to archive the sessions: one camera was set for close facial expression while the other camera was set up to record the whole scene. On the first day the prototype sensors (as described above) were used in the Danish sessions in a similar manner similar to that method used in the Swedish sessions. On the second day, a further implementation enabled gesture data information to be mapped to control "intelligent lighting". Therefore, in addition to being able to colour the image sequence, the user was able to control the X axis, Y axis and gobo pattern/colour of the robotic light from his gesture. The success of the three days of sessions encouraged the author to initiate a session on the fourth day in the Virtual Reality Panorama room for the children. This decision was confidently taken as a result of the author's previous investigations. It resulted in the prototype sensor assembly being able to control a simple Virtual Reality environment (QuickTime VR) such that each sensor achieved a functional role similar to the usual interface - a standard mouse. Thus, the prototype in this instance became a non-tangible mouse emulator so that navigation within a 2-dimension or 3-dimension environment was possible with the added bonus of being able to dwell click on certain objects to get a predetermined simple response. It was also possible to manipulate 3D objects in a similar manner.

The VR Panorama is a room with a large parabola screen onto which is (multi) projected a stereoscopic computer-generated three-dimensional image and/or environment that can be interacted with by the use of a navigational aid (usually an assembly resembling hard-wired jointed sticks or pins which the user moves to affect the assigned parameters of the projected image). Shuttered glasses are used to view the stereo image that appears blurred to the naked eye.

The programmers at CAVI adapted an existing Virtual Reality program that enabled the prototype sensor to control a projected spacecraft that was visible in strong contrasting colours on the screen. In the individual sessions, the prototype sensor was positioned behind each child's wheelchair. Two sensor heads, which were optimally adjusted and positioned each side to the child's head, were required to capture his small gestures that we were told were his best form of movement.

All children responded favourably to the visual environments. Whilst all indicated individual characteristics through their interactions by their limited body movements they all at some time achieved a level of 'aesthetic resonance'. The evaluation of the synchronized videos from the Multiple Camera Analysis

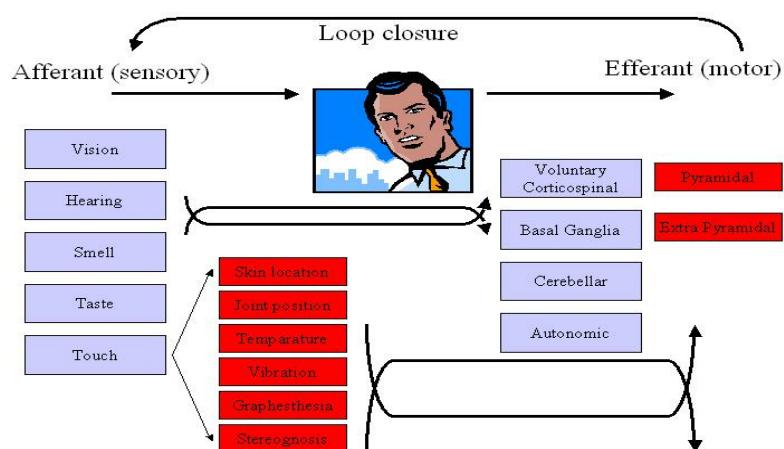
technique proved an invaluable aid: it enabled us to observe that certain movements or facial expressions which otherwise may have been overlooked allowed us to correlate the specific causal chain effect.

### 3.3 Results – Sweden

A negative aspect about the sessions in Sweden was the intervention that had to be initiated by the authors so as to set up the interactive space to the desirable sensitivity and position. This was further hindered by the size of the sensor boxes (30cm x 16 cm x 3cm) and the many wires that encumbered the working area. It was also observed by the author that often the child would lose focus on the interactive feedback due to the distraction of a small movement in the room. Future research has been planned within two rooms divided by a two-way mirror so that the child can be alone in the virtual interactive space yet still closely monitored for any signs of discomfort with related ethical rules abided by.

However, despite the negative issues raised in the paragraph above, the sessions were classified as a success: once an optimum feedback was achieved, it was obvious through the child's facial expression that a higher nuance of concentration was attained.

Our observations led us to conclude there was an overall distinct increase in motivational intent in the children. We witnessed instances where an initial subconscious (unintentional) efferent (motor) action by the child led to a definable cognitive experience (through the manipulation of the feedback as a result of the action). We would suggest that this afferant (sensory) stimulation led to an intentional (conscious) reaction resulting in the causal interactive motivation that would suggest a closure of the neural afferant/efferant loop.



**Figure 2.** The afferant/efferant loop.

### 3.4 Results - Denmark

As stated above the three days in the Experimentarium were a success and the extended prototype sensor control to 'robotic intelligent lights' from the author's earlier work again highlighted the point that a feedback of physical movement relative to physical movement proved to be a strong stimulating feedback for the users.

Three of the four children were very comfortable in the Virtual Reality Panorama environment. However, the fourth had a problem with achieving a comfortable position in the sensor space (his preferred position was on his back) that was further hindered by his feeling under the weather on both days according to the helper.

As expected, all refused to wear the shuttered glasses required for viewing the Virtual Reality projected image. This may be alleviated over time with more tries and probably – more importantly – the requirement for an adaptable fitting would be an aid as the shuttered glasses available were one size only and thus too large for the children. As a result, the projected image was driven in mono.

One session in particular resulted in an extended aesthetical resonant response from a child who very quickly demonstrated an understanding for the virtual interactive space. The recordings from this specific session were subsequently synchronized into a blended video file by the author and are accessible via url <http://media.nis.sdu.dk/video/twi-aysi.html>.

This video shows a five-year-old multi-handicapped boy who depends entirely upon his wheelchair. He can hear and has very limited vision but notices strong colours and is able to follow images with his eyes. He is unable to communicate verbally, but his helper told us that the sounds he is capable of making are indicative of enjoyment in the task in which he is involved. This is the first time he tried to control the spacecraft.

With a small gesture to the right, the rocket ship points to the right; a movement left and the rocket ship points left; a head movement down and the ship's nose tips down as if to dive; and a head movement backwards and the ship's nose tips up as if to climb. In the video an obvious conscious vigorous shake of the head from side to side is reciprocated by the spacecraft's corresponding response. The young disabled boy was only able to express himself through a single verbal expression (a sort of repeated "AYYE" phrase). While in the session and immersed in the 'aesthetic resonant' interaction, (as can be appreciated on the video), he could clearly be heard making his sounds that when interpreted by his helper as an expression of a joyful experience.

In a following experimental session the two infrared sensors were set up and programmed at long distance. They still were sending MIDI data through the same mapping network to control the VR spacecraft. With this space it was possible to still move the spacecraft but without the fixation of location of sensor head as in the short range detailed above with the five year old child. This then became a further exploration of the two sensor spaces through the interactive feedback (i.e. manipulation of the spacecraft). It was discovered to be a much more intuitive experience as body gesture, weight shift and rotation (for example) made a corresponding change to the spacecraft. Thus, a form of 2D and/or 3D navigation in Virtual Reality with non-wearable equipment at long distance, using just a small movement in the interactive space similar to the QuickTime Virtual Reality described earlier, was achievable. A possible improvement for the interaction would have been from a pilots' view.

In Sweden there were many positive responses given by both staff and families who witnessed the sessions. In Denmark, the children's helpers were positive and especially remarked upon an improved vocal communication over the following weeks by the children. A subsequent session provided further proof as a stronger verbal expression could be detected and it is proposed to utilise this as a quantitative measurable in the future research. The reactions of the child in the video provided the most obvious proof of 'aesthetic resonance' through VR visuals, matching the experience with sound we had observed in our earlier work. Virtual Environments combining sound and visual stimuli were an obvious next step.

#### 4. CONCLUSIONS

The main conclusions we have drawn from the Twi-aysi work are as follows:

- Immersion in a visual environment *can* hold similar potential to immersion in an audible environment for such children. Indeed, we were ourselves surprised how readily aesthetic resonance could be observed in such children moving within the quite crude (and sometimes silent) visual spaces we assembled.
- The attraction and advantages of using neither wearable nor touchable sensors but merely exploiting the childrens' unencumbered movement through space was readily apparent. The need for cumbersome virtual reality headsets or indeed *any* physical attachments would seem at this stage both undesirable and unnecessary for achieving satisfactory states of aesthetic resonance (see for example the video <http://media.nis.sdu.dk/video/twi-aysi.html> and pictures below).
- It was apparent that when the individual feedback was singular, certain users were more perceptible to audio while others were more perceptible to visual stimuli. When the two elements were simultaneously available and triggered through interactive captured movement, a greater degree of immersion was observed.
- Virtual Reality in its current state is not an answer because of the head/eye equipment needed to view it. However, the researchers believe that a cave environment would add to the immersive experience and as such be an aid towards 'aesthetic resonance.' The non-tangible navigation in the 2D & 3D environment that was achieved will also be implemented in further research where appropriate.

**Acknowledgements.** Ron Laborde, Bristol University, UK; Staff and children involved at both research locations in Sweden and Denmark.

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## APPENDIX

### *Extracts from the Swedish Sessions*



**Figure 3.** A cerebral palsy child achieving Aesthetic Resonance within his virtual environment as a result of responding to colour feedback to his own movement in space. The motivation that was achieved through the immersion in a visual interactive space is obvious as the variation in colour indicates a dynamic movement in all three zones and as the pictures progress down the page an increase in body movement can be observed. This session in Sweden resulted in the child pushing his physical limits without realising until afterwards when he said that he was so tired, and still he returned to the space for further interaction.

**Figure 4.** The images above show a wheelchair bound disabled child photographed from behind. The child sits in an interactive space created from three infrared sensors and in close proximity in front of a screen because of his poor eyesight. A speaker is positioned close to him for his monitoring of the audio sounds that he is manipulating through movement. He is also manipulating the colours of the "Doughnut" through moving into the interactive area of the each sensor (each designated 1 = Red, 2 = Green & 3 = Blue). The progression from upper left to bottom right in the series of photographs illustrates a progressive increase in movement that can be seen by the increase in "doughnut rings" and the colour references indicate which area/sensor is being activated. In the sessions the three different sounds being triggered were further indication.

*Extracts from the Danish Sessions*



**Figure 5.** The upper image shows the disabled child from Denmark viewed from the front camera (large image), with rear camera showing the spacecraft that he was controlling with his head gestures, (inset lowerright). A video of this session is available online. (<http://media.nis.sdu.dk/video/twi-aysi.html>).



**Figure 6.** The lower shot is a reverse image of the Virtual Reality set-up at the Panorama room CAVI (Center for Advanced Visualisation and Interactivity) in Denmark with the child in a wheelchair (centre) with two sensors (over/behind = the thin lines;) the helper is sat beside him (centre right). A camera with night vision was set up so as to capture his facial expressions and the spacecraft was projected onto the panorama screen. A second camera was set up behind to capture the total scene.

# **Multisensory 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 these spaces, is essential for the development of efficient orientation and mobility skills. Most of the information required for this mental mapping is gathered through the visual channel. Blind people lack this crucial information and in consequence face great difficulties (a) in generating efficient mental maps of spaces, and therefore (b) in navigating efficiently within these spaces. The work reported in this paper follows 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. The main goals of the study reported in this paper were: (a) The development of a multi-sensory virtual environment enabling blind people to learn about real life spaces which they are required to navigate (e.g., school, work place, public buildings); (b) A systematic study of blind people's acquisition of spatial navigation skills by means of the virtual environment; (c) A systematic study of the contribution of this mapping to blind people's spatial skills and performance in the real environment. In the paper a brief description of the virtual learning environment is presented, as well as preliminary results of two case studies of blind persons' learning process with the environment.

## **1. RATIONALE**

The ability to navigate spaces independently, safely and efficiently is a combined product of motor, sensory and cognitive skills. Normal exercise of this ability has direct influence in the individuals' quality of life. Mental mapping of spaces, and of the possible paths for navigating these spaces, is essential for the development of efficient orientation and mobility skills. Most of the information required for this mental mapping is gathered through the visual channel (Lynch, 1960). Blind people, in consequence, lack this crucial information and face 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, depending on others for continuous aid (Foulke, 1971). More than 30% of the blind do not ambulate 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 (e.g., 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

At the perceptual level, the deficiency in the visual channel should be compensated with information perceived via alternative channels. 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: " tactile refers to the sense of touch, while the broader

haptics encompasses touch as well as kinesthetic 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).

As for the conceptual level, the focus is on supporting the development of appropriate strategies for an efficient mapping of the space and the generation of navigation paths. 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 for recognizing and navigating new spaces (Fletcher, 1980).

Advanced computer technology offers new possibilities for supporting visually impaired peoples’ 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 supporting 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).

Following the assumption that the navigation in a virtual haptic environment may support blind peoples’ cognitive mapping of spaces, the main goals of the study reported in this paper were:

- (a) The development of a multisensory virtual environment enabling blind people to learn about real life spaces which they are required to navigate (e.g., school, work place, public buildings).
- (b) A systematic study of blind people’s acquisition of spatial navigation skills by means of the virtual environment.
- (c) A systematic study of the contribution of this mapping to blind people’s spatial skills and performance in real environment.

In the following sections, a brief description of the virtual learning environment will be presented, as well as preliminary results of two case studies of blind persons’ learning process with the environment.

## 2. THE VIRTUAL ENVIRONMENT

For the study we developed a multisensory virtual environment simulating real-life spaces. This virtual environment comprises two modes of operation: Developer/Teacher mode, and Learning mode.

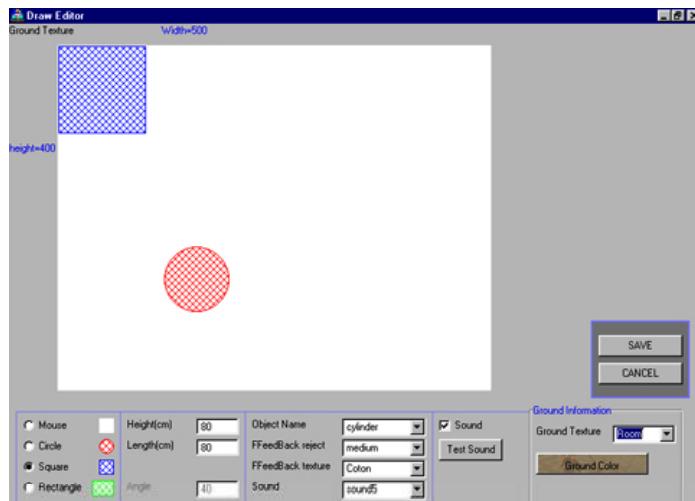
### 2.1 *Developer/Teacher Mode*

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.

3D environment builder. By using the 3D-environment editor the developer defines the physical characteristics of the space, e.g., size and form of the room, type and the size of objects (e.g., doors, windows, furniture pieces)

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., stone, parquet, grass), force fields surrounding objects, or tactile characteristics of structural components such as walls and columns (e.g., friction, texture). The attraction/rejection fields are of crucial importance to support the user’s perception of the objects’ (virtual) envelope, and the recognition of structural components is essential for the construction of an appropriate map of the whole space.

Audio feedback editor. This editor allows the attachment of sounds and auditory feedback to the objects, e.g.: “you’re facing a window” or realistic sounds (e.g., steps). Additional auditory feedback is activated whenever the user enters an object’s effect field, supplying important information with regards to the objects form (e.g., a cube, a cylinder), or aspects of its envelope (e.g., a corner, a turn).



**Figure 1.** 3D environment builder.

Figure 1 shows the environment-building-editor screen. The developer mode allows the researcher or teacher to build navigation environments of varied levels of complexity, according to instructional or research needs.

## 2.2 Learning Mode

The learning mode, or the environment within which the user works, includes two interfaces: User interface and Teacher interface.

The user interface consists of the virtual environment simulating real rooms and objects to be navigated by the users using the Force Feedback Joystick (FFJ). While navigating the environment the users interact with its components, e.g., look for the form, dimensions and relative location of objects, or identify the structural configuration of the room (e.g., location of walls, doors, windows). As part of these interactions the users get haptic feedback through the FFJ, including foot-level data equivalent to the information they get while walking real spaces. In addition the users get auditory feedback generated by a “guiding computer agent”. This audio feedback is contextualized for the particular simulated environment and is intended to provide appropriate references whenever the users get lost in the virtual space. Figure 2 shows the virtual environment.

The teacher interface comprises several features serving teachers during and after the learning session. On-screen monitors present updated information on the user’s navigation performance, e.g., position, or objects already reached. An additional feature allows the teacher to record the user’s navigation path, and replay it aftermath to analyze and evaluate the user’s performance. Figure 3 shows one user’s monitor data, and her navigation paths within the room’s space and around some objects.

## 3. BLIND SUBJECTS’ PERFORMANCE WITHIN THE MULTISENSORY VIRTUAL ENVIRONMENT AND IN THE REAL ENVIRONMENT

The research goals were to collect information on two main aspects:

1. The user’s ability to construct a cognitive map of the simulated room. Two issues were addressed:
  - User’s verbal description of the simulated room.
  - User’s ability to construct a scale model of the room.
2. The user’s ability to navigate in the real environment.

### 3.1 Method

Two subjects’ data are reported in this paper. G., is a twenty-five years old late blind, (G. became blind at the age of twenty). He has been a computer user for more than three years using voice output. G. uses a guide dog for outdoor mobility. N., is a twenty-seven years old congenital blind. She has been a computer user for one year using voice output. N. uses a long cane for outdoor mobility.

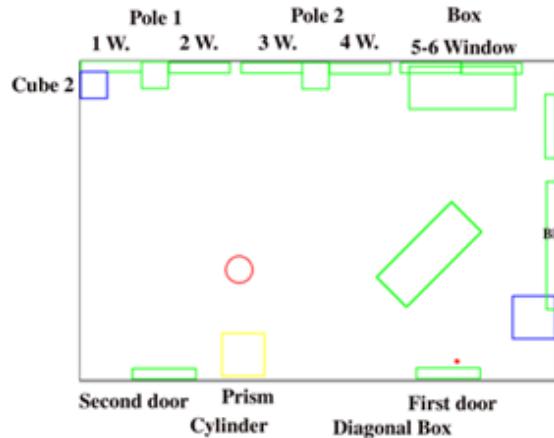
### 3.2 Procedure

The study consisted of three stages:

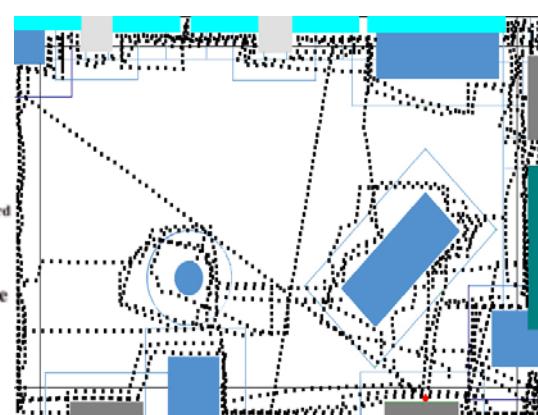
- (a) Familiarization with the virtual environment.
- (b) Navigation tasks in the virtual environment.
- (c) Navigation tasks in the real environment.

At the beginning of the familiarization with the virtual environment stage the subjects received a short explanation about its features and how to operate the FFJ. The series of tasks which were administered at this stage included: (a) free navigation; (b) directed navigation; and (c) tasks focusing on emerging difficulties. Data on the subject's performance was collected by direct observation, an open interview and by video recording. This first stage lasted about three hours (two meetings).

The navigation in the virtual environment (Figure 2) stage included three tasks: (a) exploration and recognition of the virtual environment; (b) a target-object task (e.g., walk from the starting point to the blackboard in the room); (c) a perspective-taking task (e.g., walk from the cube -in a room's corner- to the rightmost door -the usual starting point). Following the exploration task the subject was asked to give a verbal description of the environment, and to construct a scale model of it (selecting appropriate components from a large set of alternative objects and models of rooms).



**Figure 2.** The environment.



**Figure 3.** Subject's navigation path.

Several data-collection instruments served this stage: a log mechanism built-in in the computer system which stored the subject's movements within the environment; video recording; recording of the subject's verbal descriptions; the physical model built by the subject. The second stage lasted about three hours.

The navigation in the real environment stage included two tasks: (a) a target-object task (e.g., reach and identify an object on the rectangular box); (b) a perspective-taking task (e.g., walk from the rightmost door to the cylinder). Data on the subject's performance was collected by video recording and direct observation. The third stage lasted about half an hour.

## 4. RESULTS

### 4.1 Familiarization with the Virtual Environment Components

G. and N. Learned to work freely with the force feedback joystick within a short period of time, walking directly and decisively towards the objects. Regarding mobility, G. and N. could identify when they bumped into an object, or arrived to one of the room's corners. From the very first tasks they could walk around an object's corner along the walls, guided by the FFE's and the audio feedback.

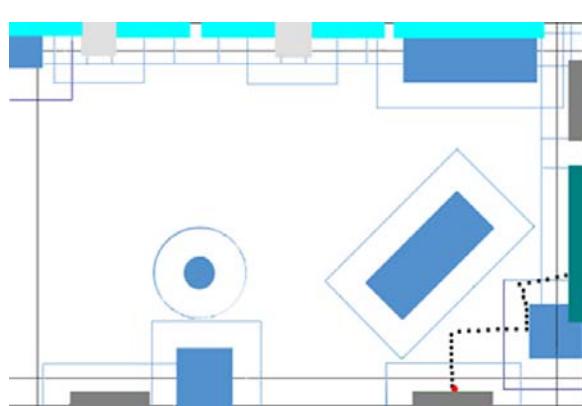
### 4.2 Navigation tasks in the virtual environment

G. And N. navigated the environment in rapid and secure movement. G. first explored the room's perimeter, (familiarization of the four walls) walking along the walls. After two circuits he returned to the starting point, and begun to explore the objects located in the room. In contrast N. explored only the room's perimeter, walking along the walls.

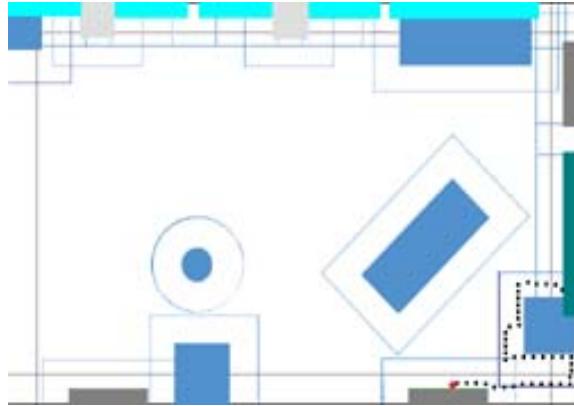
**4.2.1 Target-object task.** The Target-object task was : “walk from the starting point to the blackboard in the room”. Both subjects reached rapidly the target, by choosing a direct way.

G. performed the task applying the object-to-object strategy (knowledge of spatial relationship among two or more objects or places) and N. used the trailing strategy (Figure 6 and 7). G. and N. reached rapidly the target (20-22 seconds respectively).

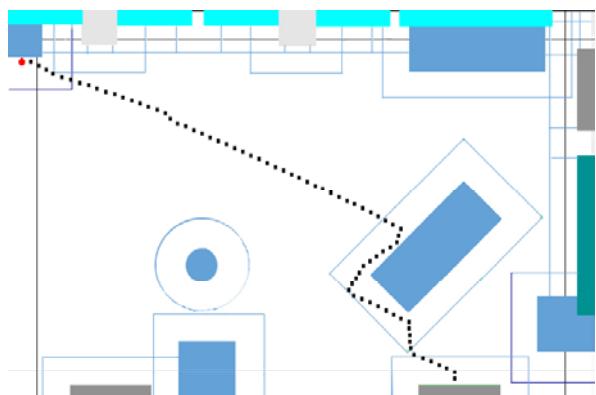
**4.2.2 Perspective-taking task.** The perspective-taking task was: “Find the door that served as starting point in the previous tasks”, the new starting point at this task was the cube in the left corner. Here once again G. performed the task applying the object-to-object strategy, and N. used the trailing strategy (Figure 8 and 9). G. reached the target in 52 seconds, and N. reached the target in 64 seconds.



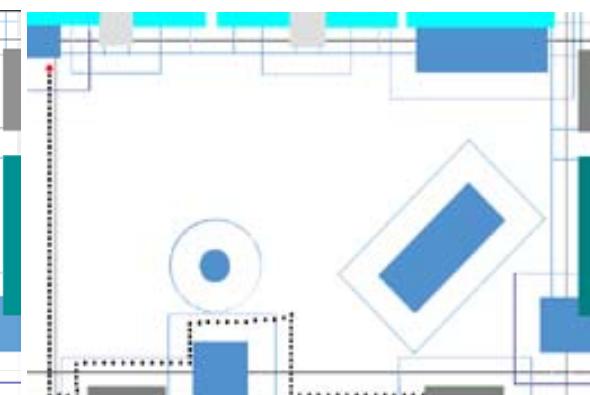
**Figure 4.** G. in Target-object task.



**Figure 5.** N. in Target-object task.



**Figure 6.** G. in perspective-taking task.



**Figure 7.** N. in perspective-taking task.

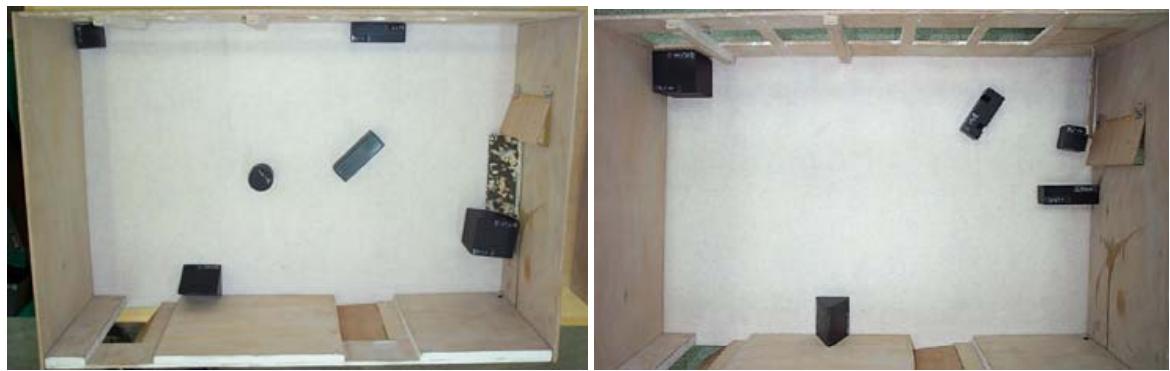
#### 4.3 Cognitive map construction

After completing the virtual environment exploration task the two subjects were asked to give a verbal description of it. Table 1 shows both subjects’ reference to structural components (e.g., columns) and objects (e.g., cube, box) in the environment.

**Table 1.** Verbal description.

Subject’s name	Structure components	Objects	Location of objects
G.	41%	71%	29%
N.	77%	86%	86%

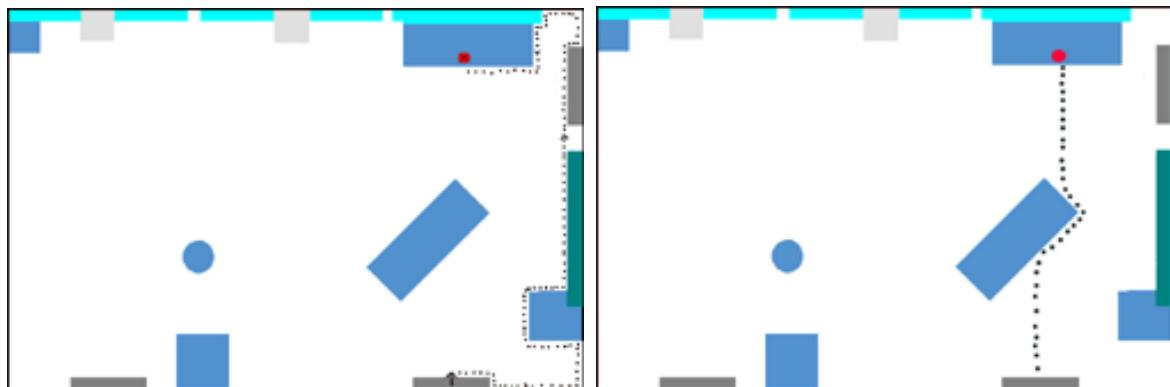
After the verbal description, the subjects were asked to construct a model of the environment. As shown in the pictures of the models composed by G. and N. (Figure 10-11), the subjects acquired a highly accurate map of the simulated environment. All salient features of the room are correct (form, number of doors, windows and columns), as well as the relative form and their location in the room.



**Figure 8-9.** Subjects' models of the virtual environment (left: N's model; right: G.'s model).

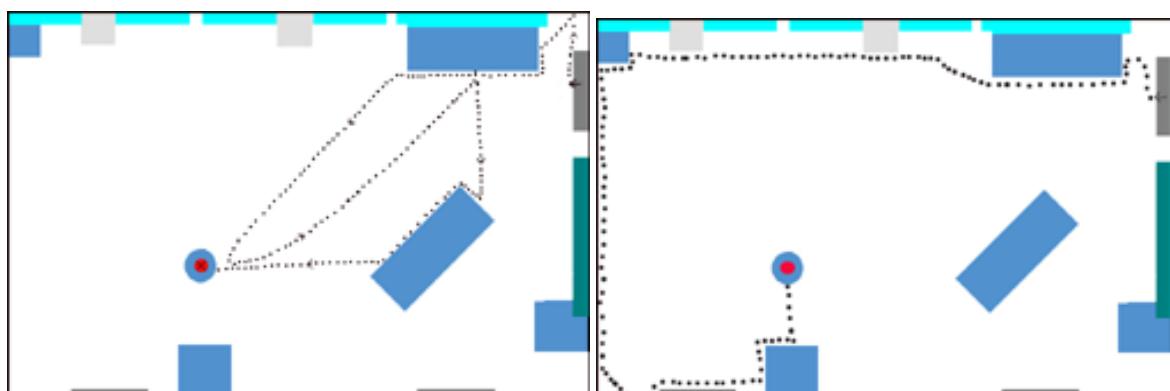
#### 4.4 Navigation tasks in the real environment

The subjects walked through the real environment from their very first time in it in a secure and decisive behaviour. At the first task ("reach and identify an object on the rectangular box"), G. used the entrance door as initial reference, and he used the trailing strategy in direct way to the box (Figure 10). He completed the task in 32 seconds. N. walked in direct way to the box using object-to-object strategy (Figure 11), She completed the task in 20 seconds.



**Figure 10.** G. Target-object task.

**Figure 11.** N. Target-object task.



**Figure 12:** G. Perspective-taking task.

**Figure 13:** N. Perspective-taking task.

At the second's task, perspective-taking ("walk from the rightmost door to the cylinder"), G. used the object to object strategy (Figure 12) walking in direct way to the cylinder and completing successfully the task in 49 seconds. N. used indirect way and trailing strategy (Figure 13), and completing successfully the task in 64 seconds.

## 5. DISCUSSION

The research results are encouraging, and the completeness and spatial accuracy of the cognitive map became evident in three revealing situations.

Navigation within the virtual room - The subjects mastered in a short time the ability to navigate the virtual environment

Cognitive map construction - after navigating the virtual room, the verbal description and the physical models built by G. and N. showed that they have developed a fairly precise map of the (simulated) space they did not know before.

Navigation in the real environment – G. and N. entered the real room which they had not known until then, and which they were not given the opportunity to explore, and they walked in it in a secure and decisive behaviour.

Based on these and other preliminary results, a systematic empirical study (involving 30 subjects) of the effects of the haptic environment on blind people's navigation abilities is currently being conducted. The results have potential implications at varied levels, for supporting blind people's acquaintance with new environments, their acquisition process of spatial knowledge and skills, and their learning of concepts and subjects for which spatial information is crucial.

**Acknowledgement.** The study presented here is partially supported by a grant from Microsoft Research Ltd.

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# ICDVRAT 2002

## Session IX. Stroke Rehabilitation and Haptics II

Chair: Paul Sharkey



# Developing assistive interfaces for motion-impaired users using cursor movement analysis in conjunction with haptic feedback

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## ABSTRACT

Following a pilot study that suggested that haptic force-feedback could, under certain conditions, lead to 20-50% improvements in time to target in a selection task, a series of experiments further investigated the use of haptic feedback modulated on the basis of cursor position. Improvement in times were obtained for specific haptic assistance techniques, particularly for the more impaired users. Cursor path data was simultaneously collected and found to identify particular features or properties of the motion-impaired cursor movement that can be specifically addressed using modulated haptic force-feedback. This suggests that parameters obtained from temporal and curvature analysis of cursor movements for haptic tasks could be used to set or adapt force-feedback in user interfaces, assisting motion impaired computer users.

## 1. INTRODUCTION

Cerebral Palsy, Muscular Dystrophy, spinal injuries and the after-effects of stroke, give rise to symptoms such as reduced strength, restricted movement and symptoms involving spasms, tremors and motion control problems. We report exploratory studies that investigate the potential for enhancement of user interfaces for such computer users by the use of modulated haptic feedback in conjunction with information derived from cursor movement parameters. We have previously reported preliminary work examined the threshold for detection and relative effectiveness of vibrotactile and force-feedback haptic interactions in a click selection task, concluding that force-feedback held more potential for assistive technology than vibrotactile particularly for highly impaired computer users (Langdon, Keates, Clarkson, and Robinson, 2000).

The use of force-feedback input devices to generate haptic and kinaesthetic sensations during interaction with a computer interface has been widely investigated for able-bodied interaction. In particular, haptic devices have been used to enhance VR interaction and tactile or tactual feedback through a mouse pointing device. For able-bodied users tactile feedback increases positioning times (Akamatsu, MacKenzie and Hasbrouc 1995), while target selection has been shown to improve with the use of attractive basin around targets and force feedback tunnels (Dennerlein, Martin and Hasser 2000, Dennerlein and Yang, 2001). Although described as tactile, interactions with force feedback mice may be better described as tactual in that the sensation results from both cutaneous and kinaesthetic feedback during mouse manipulation (e.g. Klatsky and Lederman, 1993). However, this such force-feedback also has a great deal of potential for improving the design of assistive interfaces to aid impaired movement or positioning or for rehabilitative purposes by initiating or enhancing therapeutic physical interactions.

## 2. ASSISTIVE HAPTIC INTERFACES

The existing GUI paradigm relies principally on visual feedback, often supported by sound and with minimal involvement of haptic feedback. Haptic perception is the gathering of information about objects outside of the body through the tactile and kinaesthetic senses (Klatsky and Lederman, 1993). The use of haptic feedback is restricted to the physical interaction with the specific input device, but is under-utilised. In the current graphical user interface (GUI) paradigm, icons and windows are directly manipulated but there is no

resulting tactile or kinaesthetic feedback to the manipulating limbs. This suggests a new potential interaction mode to complement the existing ones.

### *2.1 Functional Impairments*

Medical conditions such as Cerebral Palsy, Parkinson's disease, Muscular Dystrophy, spinal injuries and the after-effects of stroke, give rise to symptoms such as reduced strength, restricted movement and a continuum of impairments involving spasms, tremors and movement control problems. These populations display irregular, jerky movements, possibly in conjunction with slower, linked writhing (athetosis and chorea). They may also be poor at sequencing and co-ordinating movements (apraxic) or may have essential tremor with repetitive movements (dyskinesia) and spasms (rhythmic myoclonus). Movement impairments may arise from central nervous system dysfunction or be muscle spasms and dystonia arising from other neurological damage or dysfunction. Many of these impairments are also prevalent in the older population.

### *2.2 Haptic Assistance*

Motion-impaired users often exhibit decreased motor control and muscle strength, but not necessarily a decreased haptic sensitivity. The sensitivity of able-bodied users to haptic feedback has been demonstrated using devices such as the Phantom (e.g. Oakley, McGee and Brewster and Grey, 2000). However, this is an expensive research tool that is unlikely to be used routinely as a general-purpose interaction device. Fortunately, haptic technology is also available using the Logitech force-feedback mouse (Logitech. Ltd.) with software from the Immersion corporation (The Immersion Corporation) that is, in principle, capable of generating both cutaneous and kinaesthetic haptic interactions with the user as a result of its very wide range of movement generation capabilities.

### *2.3 Motivation*

The relative utility of haptic feedback using devices such as the force-feedback mouse has been demonstrated by the authors in work previously reported (Langdon, Keates, Clarkson, and Robinson, 2001). This paper describes experiments extending those findings by examining the improvement in users performance in a point and-click selection task with a number of haptic interface techniques and also shows how it may be possible to modify the dynamic force feedback necessary to improve interaction using parameters obtained from analysing user cursor movements. In particular, properties of a number of analytical measures of the characteristics of motion-impaired target selection movements can be related to gross performance measures in haptic interface tasks, such as time to target. The movement correlates they then represent may be (1) used to discriminate specific motion impairments or functional deficits (2) used to set the parameters of an adaptive haptic interface or (3) form the basis of specific, predictive models of motion-impaired pointing device usage.

## **3. HAPTIC EXPERIMENTS**

The volunteer participants who were involved in the study are described in Table 1. This small sample of users largely represented Cerebral Palsy populations between the ages of 20–50 and were from three post-clinical vocational rehabilitation centres of the Papworth trust in Suffolk and Cambridge in the UK. Five users, HA1, HA2, IP3, PV2 and PV3, are non-ambulant and severely impaired by tremor, spasm and weakness; PV5, PV6, PV7, PV8 and IP4 are less impaired, four being ambulant. These users can experience changes in their capability over time and may require medical treatment such as surgery during an experimental series. They become fatigued easily, despite extremely high motivation, and sometimes cannot complete trials or conditions. It is necessary for experimenters to run the trials on a long-term basis, and to develop a working relationship with the users to keep experimental conditions constant. Because of the small number of users available, repeated measures designs were generally employed. The users were both selected and screened for the experimental trials. Selection was managed to equally distribute the range of disabilities in the sample from high to medium and low impairments. Screening was also managed to exclude individuals with significant sensory or cognitive impairments that may have interfered with their capability to perform the tasks.

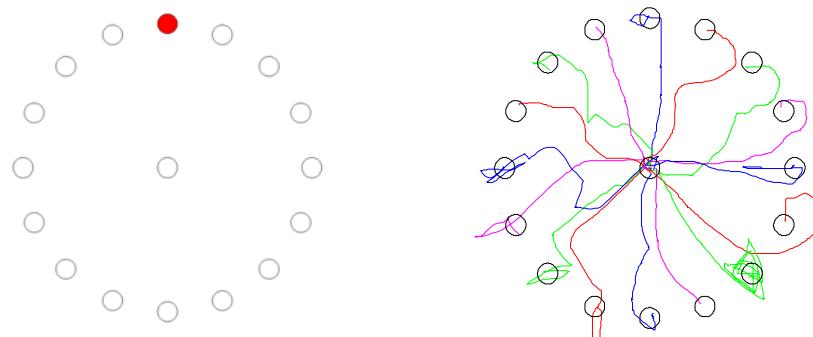
In the experiments reported, where statistical tests were possible without violation of standard assumptions, such as normality of distribution or homogeneity of variance, they were carried out and experimental power reported. Despite variability, effect sizes could be large.

**Table 1.** Participants in the haptic feedback trials.

User PV3	<i>Athetoid Cerebral Palsy, apraxia (coordination), myoclonus (spasms), Wheelchair</i>
User PV5	<i>Athetoid Cerebral Palsy, apraxia (coordination), deaf, non-speaking, Wheelchair</i>
User PV2	<i>Athetoid Cerebral Palsy, dystonia, apraxia (coordination), myoclonus (spasms) Wheelchair</i>
User PV7	<i>Friedrich's Ataxia, tremor and dyskinesia, myoclonus (spasms), Wheelchair</i>
User PV6	<i>Athetoid Cerebral Palsy, deaf, non-speaking, ambulant</i>
User PV8	<i>Athetoid Cerebral Palsy, apraxia (coordination), myoclonus (spasms), Wheelchair</i>
User IP3	<i>Head Injury, apraxia (coordination), Wheelchair</i>
User IP4	<i>Athetoid Cerebral Palsy, Ambulant</i>
User HA1	<i>Unknown, apraxia (coordination), myoclonus (spasms), Wheelchair</i>
User HA2	<i>Athetoid Cerebral Palsy, apraxia (coordination), myoclonus (spasms), Wheelchair</i>

### 3.1 Task and conditions

The task was designed for a detailed investigation of specific parameters associated with a point-and-click, selection task. The aim was to quantify the effect of force feedback on time to complete a selection. The experiment involved the users being presented with 16 target circles arranged equidistantly around a central circle on the screen. The aim was for the users to click on each target circle in a random order determined by the software (Figure 1), returning to the central target between each selection. Trials were carried out in as a set of 16, one selection for each target and blocks of three trials for each condition. This task was used in all the following experiments. Although the primary dependent variable was time to target, cursor movement trajectories were recorded at the same time for future analysis (Figure 1).

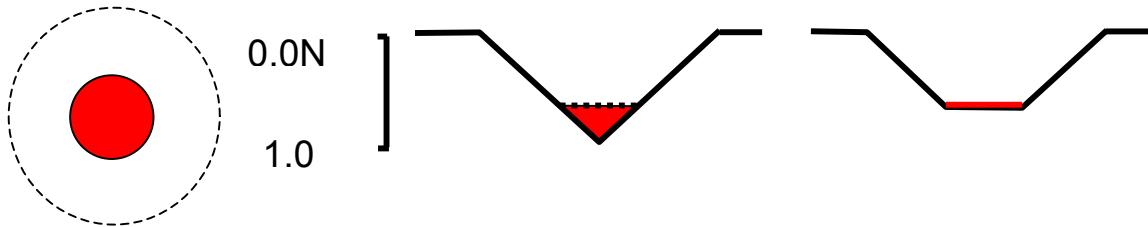


**Figure 1.** The selection task layout showing example cursor trajectories (right).

**3.1.1 Device.** The force-feedback mouse used was a development of the original FEELit Mouse marketed by the Immersion corporation and manufactured by Logitech as the "Wingman" (model E-UB3). This device generates constant force vectors at a conventionally shaped mouse mounted on a base-plate by means of an electromagnetic voice-coil activating a pantographic mechanism and controlled by an on-board processor under interactive control of a host PC. It is capable of 1.2N constant force with a 40mm square movement range that is mapped to the entire computer display. This device should not be confused with more recent haptic mice that generate only transient vibrational forces with no constant vectored component. Force-feedback within such the input device used can present constant directional forces, and also has the capability of aiding or damping user inputs, in the case of weakness, muscle spasm or tremor.

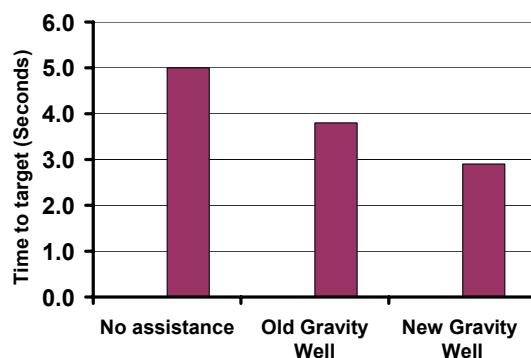
### 3.2 Attraction basins

Our previous study (Langdon, Keates Clarkson, and Robinson, 2001) examined specific parameters associated with a point-and-click, selection task. The aim was to quantify the effect of a number of variables including: pointer trails, 66Hz vibration, colour change and force feedback attraction basins, on time to complete a selection when the target was indicated by the effect. Amongst those variables was the gravity well haptic effect that gives the sensation that there is a second, larger circle around the target that corresponds to the extent of the gravity field. Entering that outer circle causes the cursor to become subject to a spring force towards the centre.



**Figure 2.** An attractive Basin with the old (right) and new (left) force profiles.

It was found that the use of a gravity well around a target improved the time taken to complete the task by approximately 10-20%. However it was also found that implementation of the gravity well as a spring force acting to the centre of the target rather than the boundary improved average time to target even more to levels approaching a 50% improvement (Figure 3). Analysis of individual differences for the users suggested that the greatest improvement occurred with the most impaired users.



**Figure 3.** Time to target for gravity well methods.

A possible explanation for the improved performance may be that overshoot, target re-entries and movements away from the centre of the target are resisted by the inwardly directed spring force. In effect, the gravity well then acts as a directional damping mechanism.

### 3.3 Force channels in the direction of the target

Haptic tunnels were intended to assist users in moving the cursor in a straight line to the target. It was expected that tunnels would help improve overall times to target by reducing deviations during navigation. It was hypothesised that the unlimited wall condition would prevent highly impaired users jumping beyond the channel wall, reducing times to target.

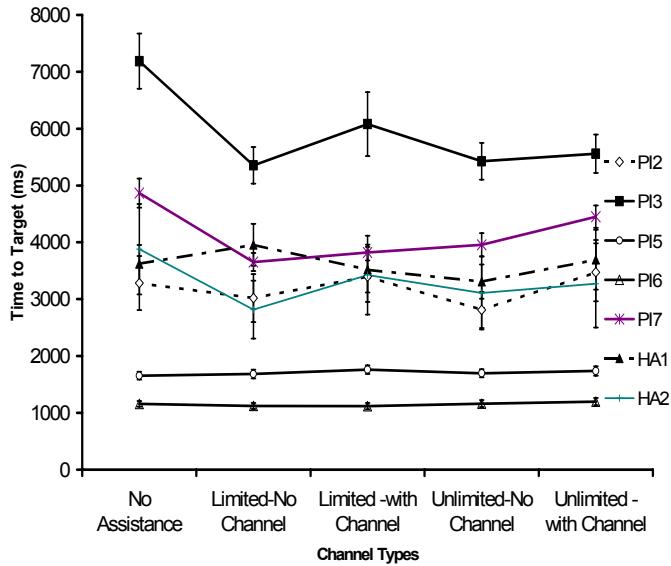


**Figure 4.** The relative wall thickness and channel width.

There were four channel conditions and one unassisted condition. Haptic tunnels have a channel width (i.e. distance between the tunnel's inside walls) and a wall thickness. When the cursor passes over a tunnel wall, a spring force pulls the cursor to the inside wall. Two conditions were presented with a 0 or 20 pixel channel width, and two conditions presented with either a 20 pixel tunnel wall thickness or an “unlimited” thickness. Hence, with 0 pixel channel width, the cursor experienced a spring force towards the centre-line of the channel and in the unlimited wall thickness condition the spring force acted toward the centre of the channel irrespective of the cursor location, with no outer limit on the wall thickness (Figure 4).

**3.3.1 Results.** There were significant differences between tunnel types overall with 36% of the variance in times accounted for by channel type. However significant non-sphericity (Greenhouse-Geisser) ( $F_{1.7, 10.2} = 3.442$ ,  $p = 0.077$ ,  $\eta^2 = 0.365$ , Power = 0.481) reduced the difference to non-significance and the observed

power from 0.77 to 0.48. Despite this, corrected pair-wise comparisons (Tukey HSD) revealed a significant difference between the “No Assistance” and “Unlimited – no Channel” conditions ( $p = 0.045$ ), and between the “Unlimited – no Channel” and “Unlimited with Channel” conditions ( $p = 0.025$ ). An ANOVA carried out using Subjects as a factor confirmed differences between highly, medium and mildly impaired users evident in the interaction diagram ( $F_{6,24} = 104.3$ ,  $p < 0.0001$ ,  $\eta^2 = 0.963$ , Power = 1.0). Further pair-wise comparisons confirmed significant differences between PI3 and all others and by PI5 and PI6 and all others (all  $p < 0.001$ ).



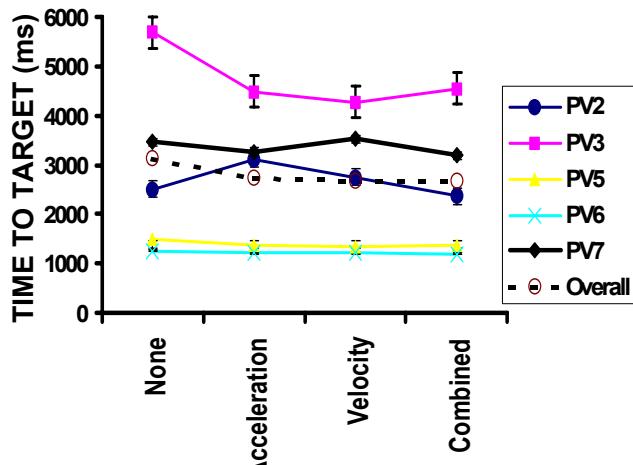
**Figure 5.** Mean time to target for 5 channel types

**3.3.2 Discussion.** There was slight evidence that the use of force channels in the direction of target was more effective than no assistance over all users. There was some evidence that the presence or absence of a central channel affected times to target indicating that constraining movement to a line was more effective than constraining movement to a tunnel. It is possible that for users experiencing difficulty navigating in a straight line, the extra freedom allowed by presence of a 20 pixel channel was a hindrance. No significant difference in times between the limited and unlimited wall thickness was observed, implying that the width of the tunnel wall does not affect performance. A possible explanation for this is that the majority of users rarely moved with sufficient force and direction to escape the tunnels. It appears that none of the tunnels give improved times for PI2, PI5, PI6, and HA1. This may be because these users do not experience difficulty moving in straight paths. However, all tunnel types appear to be of some benefit to PI3, PI7, and HA2 who had greater difficulty navigating to the target than the other users.

#### 3.4. Isotropic Damping

It was possible that the gravity well implementation was effective because of a damping effect exerted on the users’ athetoid spasms and tremors that caused the cursor to move away from the target. This would be a form of directional damping. However, another possible assistive haptic technique would involve a non-directional overall damping effective across the whole target field.

The task was performed under 4 damping conditions – *None*, *Acceleration Damping*, *Velocity Damping*, and *Combined Damping*. Non-directional damping was implemented as a viscous force that increases linearly with mouse acceleration (*Acceleration Damping*), mouse velocity (*Velocity Damping*), and a combination of the two (*Combined Damping*). The results are shown in Figure 6, with averages shown for individual users as well as overall. While the differences between overall performance levels of our motion-impaired users are evident, there appears to be no overall effect of the type of damping used, while the average times to target are not greater overall than those obtained for the attractive basins alone, as will be discussed below. The two users with low levels of impairment: PV5 and PV6 both perform at a level comparable with that of able-bodied users, whereas the most impaired user PV3, who displays spasm and athetoid movement, performs poorly but appears to show some benefit from damping. All forms of damping have a favourable effect for this user, reducing times by over 50%. Users PV7 and PV2 show intermediate levels of impairment commensurate with the degree of impairment in their targeting behavior.



**Figure 6.** Effects of Damping Types on Selection Times by Users.

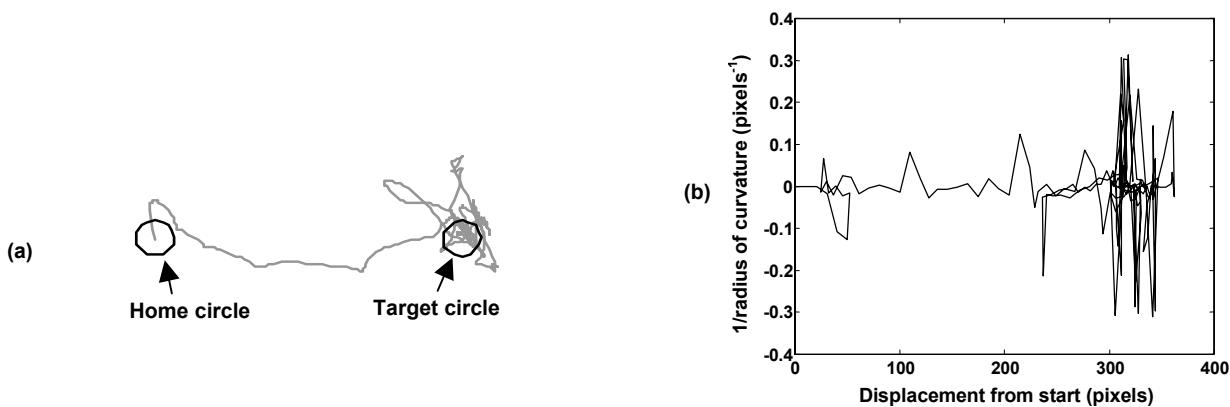
Figure 6 shows the average time to target for the damping experiment. There is no evidence for differences in performance for different damping techniques. Damping alone does not appear to have a great effect on times for users other than PV3. It may be that the nature of his impairment, which is characterised by inappropriate deviations from trajectory as a result of muscle spasms and poor coordination, may be particularly susceptible to isotropic damping. A further possibility is that resistive force of damping (up to 1.2 N) may be adequate to influence PV3's movements but ineffective at preventing the tremor of PV7. The effect of isotropic damping was to slow movement, irrespective of whether it was towards the target or not. This suggests the possibility that time to target performance may have been slowed overall despite becoming more accurate.

#### 4. CURSOR MOVEMENT ANALYSIS

Modulating the parameters of an adaptive user interface requires an understanding of the user's cursor behaviour during an interaction. Hence, by studying cursor trajectories throughout a target selection task, differences in the cursor movement behaviour of users may be identified and related to gross performance. A range of cursor characterisation measures were examined. An example measure: the radius of curvature of the cursor path, was developed in conjunction with observations of motion impaired movements made in the previous experiments.

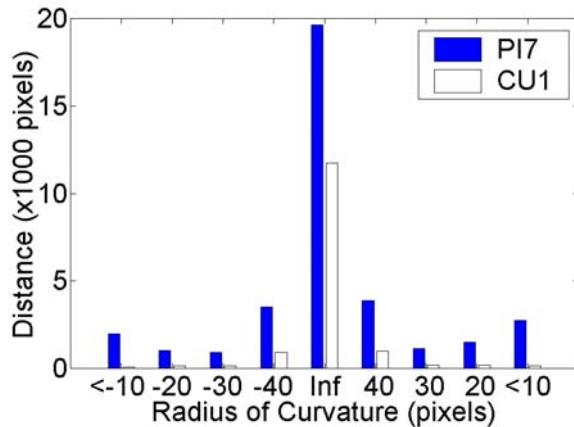
##### 4.1 Radius of Curvature

A curved path can be represented geometrically as a series of differential arc segments, each formed from the arc of an associated circle having a particular radius of curvature (Hibbeler, 1998). Small radii indicate highly curved regions of a path, and large radii indicate relatively straight regions.



**Figure 7.** The radius of curvature measure.

The radius of curvature along a path can provide information about the number and proximity of curves in the path at a chosen scale. Figure 7a shows a representative cursor path for user PV7 using the Wingman mouse without gravity-well haptic assistance. Rather than the smooth ballistic and homing movement phases displayed by able-bodied users, this trace displays a modified ballistic and homing phases with an erratic progress to target followed by multiple attempts and failures to select the target. This behaviour is captured by the curvature measure graph in Figure 7b which shows the reciprocal of radius of curvature (approximated for an arc length of 10 pixels) plotted against displacement from the start point. High values of this measure indicate a small curvatures or “kinks” in a smooth trajectory and it can be seen that the measure is highly sensitive to this aspect the movements of motion impaired user.



**Figure 8.** Distance Travelled for a Range of Curvatures for one user (PV7) and an able-bodied comparison(CU1).

Calculating this measure at a range of scales, corresponding to different arc lengths allows a frequency histogram to be constructed based on the number of times each scale crossed a threshold. Such a measure reveals differences in cursor behaviour that can be used to discriminate individuals or impairment type. Other measures under test include: distance travelled for a range of cursor speeds; and distance travelled for a range of radii from target (Hwang, Langdon, Keates, Clarkson, and Robinson, 2002).

## 5. DISCUSSION

Overall a strong positive effect of using force-feedback assistive techniques to enhance interaction was observed for our sample of motion-impaired users. The force feedback appeared to be of most benefit to the more severely impaired, especially those with difficulty performing targeting actions. These assistive techniques serve to minimise the number of inappropriate movements away from the target centre by presenting directional resistive forces for the former and minimising distracting and disruptive clicking movements for the latter. The effectiveness of isotropic damping was greatest for the user with the most spasm and athetoid movement and relatively ineffective for other users. This suggests that force-feedback damping may be most effective when its direction and timing can be linked to a users specific cursor movement patterns. Using a user’s cursor measure profile, it may be possible for the interface to detect and compensate for uncontrolled movements such as spasm. For example, appropriate levels of isotropic damping could be generated at the point of the movement where imminent target entry was indicated by measures such as increased frequency of high curvature movements. Likewise, attraction basins could be activated at a given target and their size or strength modified by an algorithm set to detect such “cues” using a range of cursor movement measures. This process of detection might be carried out adaptively during the course of a number of movements or could be pre-set during a system training period in a predictive approach. A number of strategies for assisting motion-impaired steering movement are suggested by the specific findings of the cursor measure comparison. These include: (1) applying directional resistance to reduce high radius of curvature movements during the movement trajectory. (2) reducing the incidence of deviations from direct movement to target by applying resistive movement in a haptic “tunnel”.

## 6. CONCLUSIONS

A number of assistive techniques; namely, attraction basins, force tunnels and isotropic damping were tested and shown to improve the performance of motion-impaired computer users in a selection task as measured by gross performance measures such as time to target. In conjunction with this, the patterns of cursor movement during the same tasks were analysed using a measures that was deemed capable of discriminating specific characteristics of motion impaired movement resulting from spasm and athetosis. The results suggested that such measures were, in principle, capable of discriminating individual users impairments, impairment types and task specific impairments. These measures, such as curvature identify particular features or properties of the motion-impaired movement that could be specifically addressed using modulated haptic force-feedback techniques such as attraction basins, isotropic damping, steering tunnelling and movement curvature limiting. Evaluating the effectiveness of these techniques will require their implementation in a realistic GUI test application, such as an assistive keyboard. The availability of comparatively cheap force feedback devices, such as the Logitech force-feedback mouse, means that the use of haptic interaction has the potential to become extremely important technology for enabling universal access to computers in the future.

**Acknowledgements.** The authors would like to thank the volunteers and staff of the Ipswich Progression Centre and the Papworth Trust. This research is funded in part by the EPSRC, the Canadian Cambridge Trust, and NSERC.

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# Assessing the utility of dual finger haptic interaction with 3D virtual environments for blind people

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## ABSTRACT

Whereas the rapid growth in use of 3 dimensional computer images has proved to be of significant value to many computer users, they have remained totally inaccessible to blind people. The EU GRAB project is seeking to establish the degree to which a dual-finger haptic interface, augmented by audio input and output, can provide non-visual access to this important area of the information world. The haptic interface itself is an entirely new development controlled by a powerful haptic modelling tool. Validation of such a device is a complex procedure, not least because it falls entirely outside of the experience of most users.

## 1. INTRODUCTION

Of our five senses, vision is normally considered to be the most important in our interactions with our world. The eye has an amazing ability to rapidly adjust to different light levels and to zoom between viewing a great vista to examining a close object in detail. Of even greater significance is its capacity to work with the brain to collect, process and make sense of immense amounts of information. Any impairment to the visual path, whether caused, for instance, by a damage to the eye or by being in the dark, significantly reduces a person's ability to interact with their environment. The obvious implications of lost or diminished vision are difficulties in reading or moving around safely, with consequent obstacles to learning and being employed. Since increasing blindness afflicts many people in old age, the vast majority of blind people being over the age of 75, emotional effects such as social isolation and not seeing their grandchild grow up can be of far more consequence. One of the challenges for our use of technology is to develop solutions that address the issues that people really face in their lives and accept that these may not always coincide with the clear strengths of the technology itself.

The general approach to combating the effects of visual impairment has been to improve the visual environment or to shift modalities to the other senses. Any comparison will always show how limited the processing ability of hearing and touch is in relation to vision. That is neither to deny the specific and peculiar advantages of the other senses nor their ability to augment vision. This does mean, however, that people will generally use whatever residual vision they have in preference to resorting to audio or tactial material. The focus of this work is on those for whom vision is no longer or never has been an option for assimilating information by assessing to what extent a haptic and audio virtual environment can provide a valid and useful alternative.

This paper is based on contributions from members of the European funded IST project GRAB (IST-2000-27510). Further details of the project and the consortium can be found at [www.grab-eu.com](http://www.grab-eu.com).

## 2. COGNITION

### 2.1 *Haptic sensing*

Perceptions of the world generally arise as a combination of correlated input across several of the senses. Haptic devices are frequently used in conjunction with sight, and information regarding object properties has been shown to be differentially salient under conditions of pure haptic exploration, and haptic and visual exploration (Wall and Harwin 2000). Information about an object's shape is easily extracted by visual means, whereas to gather this information haptically "requires the execution of the 'contour following' exploratory process" (Klatzky, Lederman and Reed 1987)), which puts a large demand on the user's memory for temporally varying signals, plus, the process is time consuming. In other words, exploring objects by sight results in an almost instantaneous understanding of its shape. But when objects are explored purely haptically, exploration is serial thus, more time-consuming and requiring more use of memory.

Exploration is an important part of the perception process of all senses. When exploring an object in a natural tactile environment all the fingers on both hands are involved. At each finger some extended skin area is in contact with the object providing the explorer with information. However, the exploration of virtual objects with a haptic device is different, as information at each moment is restricted to one point of the surface of the virtual object. In addition, the observer contacts it through either a stylus or a thimble meaning there is no skin contact. When the thimble is used only one finger is involved. The spatially distributed pressure on the finger tip within the thimble does not carry any information about the form of the virtual object as the latter is represented at each time by only one point and so the loss of cutaneous feedback will restrict the user (Jansson et al.1999).

One of the things determining the usefulness of a haptic device is whether it benefits, or adds to the visual experience of virtual environments. If haptic devices are to be assessed for their potential for blind people then usefulness "must be judged by partly different criteria, as haptics have to work without visual guidance" (Jansson et al.1999). But the usefulness is a combination of the haptic device and the software application, as stated by Kirkpatrick and Douglas (2000) "One of the most important attributes of a haptic device such as the PHANTOM is its usability. However a haptic device by itself has neither good nor bad usability. Rather, usability is determined by the relationship between a task and an interface, which includes the haptic device as one hardware component of an integrated hardware and software system." Not all the applications may be suitable for a given haptic device. Special care has to be taken in order to define suitable applications for each haptic device.

When visual information about an object is readily available and the user is able to see it (i.e. they are not blind or severely visually impaired) then the global shape and structural cues become the defining properties of an object. On the other hand if an object is explored purely haptically then material cues such as texture and compliance have a greater significance (Wall and Harwin 2000). Similarly, Katz (1989) states that in human sensing and manipulation of everyday objects "the perception of surface texture is fundamental to accurate identification of an object."

Surface texture is clearly regarded as important by many researchers. The fact that devices such as that proposed for GRAB involve inserting the finger into a thimble reduces the amount of surface information directly available to the surface of the finger. In addition, the thimble of the PHANTOM does not carry information about the form of objects because objects can only be presented through one point at a time. Jansson et al. (1999) point out also that "even if information is obtained from (changing) muscles, tendons and joints, the loss of cutaneous information may mean an important restriction". This is supported by other researchers, for example "the availability of an interface system capable of generating adequate cutaneous stimuli on the user's hand is a primary need when the problem of the recognition of features of an object is translated from a real to a virtual environment" (Bergamasco 1997).

### 2.2 *Multimodal representation*

With the increasing availability of auditory and haptic means of interaction it is not unusual for developers to try to incorporate many modalities in interfaces rather than the purely visual. Blind people must depend on non-visual senses to help in locating and identifying objects and people, and to help provide an overall conceptual organisation of spatial environments. Grabowski and Barner (1998) showed the feasibility of combining the sense of touch, using the PHANTOM, and representative soundscapes to develop visualisation aids for the blind and visually impaired people.

Determining the role or roles of other senses in compensating for the loss of visual information requires careful examination, because it is not enough to merely replace visual information with audio and/or textural information. According to McGee, Gray and Brewster (2000), the user can be powerfully affected when information presented in different modalities is combined to become multimodal. They argue that “providing interface designers with the means to implement haptic-audio interfaces might result in adverse effects to interaction unless they are also equipped with structural knowledge on how to select effective combinations of such information”. They add that when two or more modalities are combined, the resulting perception may be weaker, stronger, or altogether different. Therefore effects of combining haptic and audio information “must be systematically explored to realise the potential of haptic-audio interfaces as well as to avoid creating interfaces that afford poor interaction”.

Multimodal representation of information is currently in an exploratory stage. The majority of research seems to conclude that more research is required in order to clearly identify how to improve such systems and representations of visual information. There are a number of areas that stand out as being important considerations for haptic exploration in a virtual environment with or without audio and textural enhancement. Firstly there is the issue of the degree of cutaneous feedback available through a limited number of cutaneous receptors. Exploration without sight is sequential and therefore issues about the time it takes to explore and the memory required to do so are pertinent issues. Additionally there is the issue of determining how multimodal feedback should be combined, in order to be helpful to the user, rather than weakening the feedback. It must be remembered that visual exploration that is enhanced by haptic and audio feedback is very different to haptic and audio exploration when visual feedback to the user is not possible. The effective representation of information that is normally presented visually is not a matter of directly transferring that information into a different mode. Contextual user issues and requirements need to be fully understood, and the problems that past researchers have experienced in presenting haptic, textural and audio information should be taken into consideration in the development of new devices and in ongoing research.

### 3. USER NEEDS

Identifying users' needs of a new technology is always difficult since few of us can articulate our needs of something we know little about. The approach within GRAB was to discuss areas of need and aspiration with groups of potential users.

All focus group participants were very interested in the GRAB device and its potential. Many had very high expectations of what the device would be capable. Some participants, for example, felt that the technology would enable them to explore the fine detail of sculptures, complex screen layouts or explore scanned photographs in 3D, even using the device to recreate parts hidden from the camera. Although some participants felt that the device would enable exploration of this kind, many participants questioned the ability of the device, expressing reservations for example about who would provide the content to such a system. The groups considered three particular applications:

- When discussing **3D Mobility Maps**, participants were unsure about the usefulness of the 3D element in what is, primarily, a symbolic representation. There was concern about how the content of such a device could be made complete and updated regularly enough and a feeling that such a device would need to be portable.
- Many participants were very enthusiastic when discussing **Games**. They were particularly excited about the prospect for blind people to play games that they cannot play in any other way. These games included target and searching games that could be combined with audio to indicate state of play and whether users were near target and so on. Adventure games, which, for example, comprise a series of rooms and tasks where objects need to be picked up before players can proceed were suggested, again with audio to indicate objects, state of play and so on.
- The more ‘technical’ participants showed great interest and high expectations of a **Haptic GUI**. Some participants liked the idea of being able to explore the entire screen in great detail, for example, being able to feel the word and emblems that are on icons. However, even with such interest in the concept, they seemed to feel that in day-to-day work they would not use the device for this kind of application, since quicker methods like the speech technology are already in use.

These focus groups added many potential applications to an already long list proposed by the developers. However, further analysis has called many of these into question either because they are not technically

achievable, the cognitive load is prohibitive or because there are far simpler alternatives, many of which are already in use. Before these issues can be resolved, there is a need to gain a far better understanding about the capabilities of the device and its use.

## 4. INITIAL STUDIES

### 4.1 Simple object layouts

A series of studies were undertaken in order to obtain some indications of users aptitude in exploring objects and layouts through limited tactal sensing. Three layouts were constructed by gluing children's building blocks to a baseboard. A fourth abstract object consisted of a wooden ball threaded on a rope that was passed through a slot in a piece of wood and its ends terminated in wooden disks. Participants were asked to explore each layout in turn either with whole hand, wearing gloves, restricted to using two fingers or using thimbles. They then gave an overall description of the layout and stated how many items it contained. Further questions probed how easy they had felt the test to be, whether they were happy with the exploration time, if they thought that audio feedback would have helped and how useful they found information from touch alone. Sighted or partially sighted participants, who had been blindfolded, were asked to remove their blindfold and rate how good they felt their mental representation of the layout was in comparison with what they could see. Blind participants were given a verbal description and asked to re-explore it using two hands, and then asked to rate how accurate their original mental representation had been.

Although the average time to explore the layouts using thimbles was over twice as long as that with whole hands, it was more significant that participants did not feel that they had obtained an accurate representation. The thimbles were used since they partially simulated the proposed device by restricting the cutaneous feedback, which is the most sensitive part of the sense of touch. Participants found:

- Lack of sensation
- Difficulty determining size
- Curves being over-accentuated
- Difficulty determining shapes
- Difficulty determining angles
- Difficulty judging distance

Those who preferred thumb and index finger said that they were able to grip objects and judge distances better and they said it felt more 'natural' than with two index fingers. Those who preferred two index fingers seemed to be able to judge distance and 'arrangement' better by holding one finger still and exploring with the other.

Many participants felt that audio would help to some extent. The type of audio feedback described as being useful included a description of the layout and an indication of how many items the layout consisted of. Other participants did not feel that audio feedback would help, particularly in those conditions where thimbles were not used. Generally, they felt that the need for audio feedback depended on the situation and whether it was vital to get all the information (for example in an exam situation). Touch alone was considered to be useful as long as thimbles were not used. One blind participant said, "if there was an audio description, then what would I need to feel it for?"

No differences were evident in the findings with respect to visual status. It is important to remember in tests of this kind that it is not possible to understand completely what a blind person's mental representation is. On the other hand, sighted and partially sighted participants are able to 'check' their mental representation.

### 4.2 Three dimensional objects

In a second set of experiments, participants explored plaster busts of Bach and Mozart. They knew the type of object but had to glean information about the detail. Audio help was provided by identifying which part of the bust was being touched. Those who had some visual reference, i.e. had seen what a bust looked like, found it significantly easier to identify the difference between Bach's wig and Mozart's hair, though other distinguishing marks were missed entirely. The problem for a congenitally blind person was summed up by one of the participants:

*"It's difficult to perceive. It's difficult enough to relate the real thing to an image, so this would be another few steps removed. Trying to get someone like me to understand art is like getting someone who only speaks a foreign language to appreciate my poetry. I do not possess colours and perspective, which is the language of sight. I don't have that."*

It is also clear that, while a bust may produce a good visual likeness, the feel of a real head is nothing like its plaster representation. A congenitally blind person has to learn visual shapes of real objects without ever sensing them directly. This may suggest that a haptic device of the type proposed in this project is unlikely to be suitable as an exploration tool. Effective applications may make greater use of the user's ability to interact with and modify the virtual environment.

## 5. THE GRAB SYSTEM

### 5.1 Description

The GRAB application is based on the integration of three tools:

- A two-finger 3D force-feedback **Haptic Interface** developed by PERCRO.
- **Audio Interaction** using speech recognition and voice synthesis (IBM ViaVoice)
- The **Haptic Modeller** developed by LABEIN to allow the interaction with any 3D virtual object through haptic stimuli, sounds aids and speech recognition.

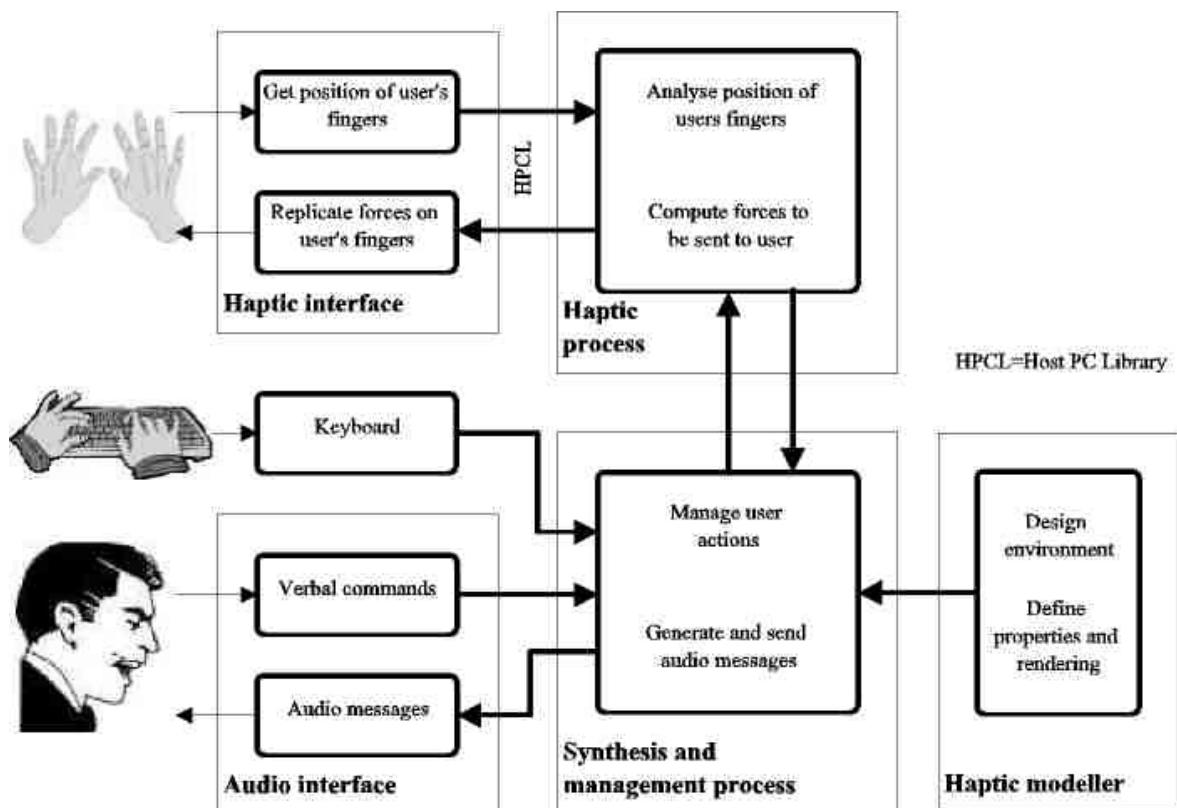


Figure 1 System view of the GRAB Haptic and Audio Virtual Environment

The user inserts two fingers (the thumb and index or both index fingers) into the thimbles of the haptic interface and moves them through the virtual workspace. The user can interact with the virtual objects, listen to audio messages and execute verbal or keyboard commands. The operator screen shows the virtual objects and the points that represent the positions of the user's fingers within the virtual space. The various elements of the system include:

- The properties and position of all objects within the virtual environment are defined by the **Haptic Modeller**.
- Using information about the position of the user's fingers, the **Synthesis and Management Process**:
  - Renders the virtual environment, including any dynamic modifications to, for instance, the placement of objects.
  - Manages the actions required by the user.

- Generates and sends both speech and non-speech audio messages either automatically, based on object properties, or at user request.
- User commands can be given either by voice through the **Audio Interface** or by keyboard.
- The control of the **Haptic Interface** is maintained by the **Haptic Process** executing the cycle of “get position – analysis position – replicate force” at a constant frequency of 1kHz.

### 5.2 Functionality

The first prototype of the GRAB application provides the following functionality:

- Simulation of different forces that: represent **contact** with an object, modified by properties such as stiffness, texture and stickiness of objects whose size is very small or very large.
- **Panning** across the virtual environment if its size is greater than the physical workspace.

The initial implementation will include a number of test scenarios in which each function is, as far as possible, isolated to facilitate user validation. The functions will also be combined to produce an adventure style game requiring the user to navigate through several rooms on two floors. The user will encounter a variety of obstacles, including time delay triggers that will have to be reset within a given period.

## 6. HAPTIC INTERFACE

### 6.1 Mechanical Features

The haptic interface consists of two co-ordinated arms, each with six degrees of freedom, allowing relevant forces to be exerted on the user's fingers as shown in Figure 2. Each arm consists of a passive gimble attached to an actuated serial chain. The specific differential kinematics achieves a high degree of stiffness and isotropy while still exhibiting low inertia on the fingertips. The interface has been designed so that the joint workspace of the two arms can cover a large portion of the desktop (arranged as a parallelepiped of 600mm wide, 400mm height, and 400mm depth). The system is equipped with high performance DC motors that directly drive a cable transmission, thus avoiding problems of backlash. While operating in the centre of the workspace, a weight counterbalances the moving mass of the barrel, thereby reducing the amount of torque required from the motors. The motors have been designed such that the interface can exert a force of at least 4N throughout the workspace, though higher figures can be achieved when operating in the centre or the workspace. A peak force of 12N can be achieved for a short time. The system is equipped with a set of encoders for measuring the finger position with a spatial resolution of better than 100µm worst case. The device is designed to be transparent to the user by minimising extraneous forces generated by the interface.



**Figure 2** The haptic interface in use

## 6.2 Control Features

The moving arms are provided with semi-embedded drivers that take care of all the basic control aspects for managing the interface. Control and driver units generate the required forces on the fingertips while measuring their position in the workspace. Moreover, the control unit compensates for all the non-linear features related to the interface control and the force generation, such as the gravitation compensation, the active friction compensation and the interface kinematics. The whole control system implements a real time scheduler and runs at a nominal frequency of 5KHz, which was chosen to avoid stability problems at contact even when the arm is remotely controlled. The system can be driven by attaching its data port to the parallel port of a remote computer running any type of operating system. A set of libraries and drivers allow the control of the haptic interface at a frequency of 1kHz, though this could be increased to 14kHz if required.

The controller has been designed to incorporate several safety features, particularly bearing in mind the needs of blind people. When the interface is moving autonomously, the controller limits the maximum velocity and forces that can be exerted on the joints. This minimises risk of injury even if the user gets too close to the device or touches it improperly. The interface can be configured to warn the user of specific actions. The power to the motors is disabled if the emergency pushbutton is operated or the interface is been left unattended for a more than an hour.

## 7. VALIDATION PLAN

### 7.1 Aims

The developers of the GRAB device have designed several algorithms that simulate various properties of virtual objects through forces generated on two points. The aim of the validation is to confirm that the implementation of these algorithms is effective for users of the prototype. The findings of the validation testing will be used to decide whether the functional requirements have been met adequately and whether their usability meets the success criteria. The outcome will contribute to a wider feasibility report.

### 7.2 Participants for validation testing

In order to obtain representative results, participants will be drawn from groups of people with varying sight problems, including:

- Congenitally blind people
- Adventitiously blind people
- Partially sighted people
- Sighted people

Previous research suggests that people who have or have had some sight tend to use their visual memory even when carrying out a haptic task. The inclusion of congenitally blind people may indicate how important such visual memory is when using a system such as the GRAB prototype.

It has been suggested that a person's 'haptic aptitude', that is their ability to use touch, may significantly affect how well they can use the GRAB device. Factors that may indicate such an aptitude include whether they like tactful exploration and competency in reading □aille or tactile graphs and diagrams. Although people who regularly use tactful material do not necessarily have a more sensitive sense of touch, that sense is trained to be effective. These factors will be checked as part of the participant characterisation.

### 7.3 General outline of procedure

The test sessions will consist of three stages.

- **Familiarisation:** During this stage the user will receive information about the main features of the system and broadly how it works. They will be given a short training session to become familiar with the device. This will mean that the system is tested after the initial 'novelty' period.
- **Test stage:** The user will be asked to work through a set of scenarios to test the main functionalities of the system, including the audio help features. Various aspects of their performance will be recorded including time, accuracy and error rates.
- **Subjective testing:** Participants will be asked how easy the system was to use and how satisfied they were with various parts of the experience. They will also be asked for their subjective

viewpoint of the potential usefulness of the system.

#### 7.4 Professionals' validation testing

A second group of participants will include a sample of professionals composed of people from a variety of industry sectors, but all of who work closely with blind and partially sighted people. These participants will be drawn from groups such as rehabilitation workers, mobility trainers, teachers, IT professionals and psychologists. This group will help to assess the possible usefulness of the device in their work. Although some of the testing may include similar scenarios as used in the first set, there will also be opportunities to test the ability of the professionals to design virtual environments for use with the device.

The procedure for testing with professionals will be the same as for the other participants. That is, a familiarisation session, followed by an experimental testing session, followed by a gathering of subjective opinions from participants. This final session will focus on the perceived usefulness of the system, the perceived contribution of the system to their work and the perceived ability of the device to increase the quality of their work.

#### 7.5 Reporting

The validation findings will be combined with a detailed review of possible implementation scenarios, the potential market size and estimated costs in order to produce the final feasibility report. One of the main outcomes of this phase of the project will be a list of proposed applications in the general areas of learning, employment, mobility, leisure and daily living. The first application being built is a realisation of an adventure game based on exploring several rooms that contain hidden dangers and methods to neutralise them.

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# **Assessing stroke patients' ability to remember to perform actions in the future using virtual reality**

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## **ABSTRACT**

Difficulties in assessing prospective memory (remembering to perform actions in the future) have contributed to a dearth of empirical evidence as to whether stroke patients are impaired at prospective memory tasks. A virtual environment was used to assess stroke patients' and age-matched control participants' performance of realistic event-based, time-based and activity-based prospective memory tasks. Stroke patients were impaired compared to controls at all the prospective memory tasks, but less impaired at the time-based task. Their prospective memory was more impaired than their retrospective memory, assessed by a free recall test. These results will be useful in directing future stroke rehabilitation strategies to focus on specific memory impairments.

## **1. INTRODUCTION**

Impaired memory is one of the most disabling consequences of stroke (Sohlberg, et al, 1994) and a major target of cognitive rehabilitation. One of the most disabling forms of memory impairment is the inability to remember to perform actions in the future (prospective memory failure). Kvavilashvili & Ellis (1996) suggest that all prospective memory retrieval occasions may be classified as either event-based, time-based or activity-based. In event-based tasks, an action is required to be performed at a cue (e.g. relaying a message when you see a friend); in time-based tasks, an action is required at a previously specified future time (e.g. keeping an appointment at 3 p.m.); in activity-based tasks, an action is required before or after performing an activity oneself (e.g. switching off the stove after cooking).

It is assumed that many stroke patients have problems with their prospective memory, but there is a dearth of empirical evidence to support this assumption (Titov & Knight, 2000). No known study has compared the performance of stroke patients and age-matched controls to investigate whether stroke patients show significant deficits in performing different types of prospective memory task. A possible reason for this lack of empirical research is that it is difficult to perform a realistic and controlled assessment of stroke patients' prospective memory ability in a rehabilitation setting. This problem may be overcome by assessing prospective memory ability using virtual reality (VR).

VR is an interactive computer technology that can create the illusion of being in an artificial world. It provides a detailed three-dimensional computer-generated representation of the world that can be manipulated, and within which one can move around. A form of VR may be presented on a computer monitor and can be explored and manipulated using a joystick or other control device. Virtual environments using this technology can be designed to represent any real-life situation and programmed to record accurate measurements of performance within them. They are able to combine aspects of the realism of "naturalistic" studies with the control of laboratory-based studies.

There is considerable potential for using these virtual environments in the assessment and rehabilitation of people with brain damage which is only just beginning to be realised (see Rose & Foreman, 1999, for a review). For example, they have been used in the assessment and rehabilitation of people with traumatic

brain injury (Christiansen, et al. 1998; Davies, et al., 1998), executive function disorders (Mendozzi, et al. 1998), contralateral neglect (Wann, et al., 1997), and temporal lobectomy (Morris, et al., 2000). Pertinent to the proposed investigation, they have been used to study memory processes in vascular brain injury patients (e.g. Rose, et al., 1999), and in memory rehabilitation of a vascular brain injury patient with amnesia (Brooks, et al., 1999). A virtual environment using this technology would appear to be an ideal medium for assessing the prospective memory ability of stroke patients.

This study therefore used a virtual environment to assess the ability of stroke patients and age-matched control participants to perform event-based, time-based and activity-based prospective memory tasks.

## 2. METHOD

### 1.1 Participants

Thirty-six stroke patients from the Stroke Rehabilitation Unit at the Kent and Canterbury Hospital, Canterbury, and 22 age-matched adults (mainly relatives of the stroke patients) participated in the study. The criterion for selection of the stroke patients was that, in the opinion of the physiotherapist, they were cognitively able to perform the task.

### 1.2 Equipment and Materials

The virtual environment was a four-room bungalow. It was constructed using Superscape VRT software, run on a desktop computer, explored using a joystick, and manipulated using a mouse. In the bungalow were 30 items with "to go" labels attached to them. Five of these items had glass components (computer, wine rack, television, grandfather clock and microwave). In the hall was a digital clock with a red button to its left.

A set of 12 photographs of common objects, e.g. a pen, a bus, were used in a free recall test.

A ten item questionnaire about typical prospective memory tasks, e.g. "How often do you set off to do something then can't remember what?", "How often do you forget to take medication?", each item followed by seven rating boxes ranging from "Never" to "Always", was used in a subjective prospective memory assessment.

### 1.3 Procedure

Participants were initially asked their age and the number of years they had spent in full-time education. They were also asked if they would lend the experimenter a personal item, e.g. a watch, which they should remember to ask to be returned at the end of the study.

They were then given a free recall test in which they were shown 12 photographs of common objects, one photograph at a time for three seconds each. As soon as they had seen all 12 photographs, they were asked to recall any objects they could remember and were given as long as they required for this task.

In the prospective memory task, participants were first informed that the owner of the virtual bungalow was moving to a larger house with a hall and seven rooms (lounge, dining room, nursery, kitchen, study, music room and bedroom) and that he had put "to go" labels on the furniture and objects to be moved. Their task was to organise these items for the removal men by asking the experimenter to move any items that they considered should go in each of the rooms of the new house in turn beginning with the new hall. (They were given a list of the rooms in the new house to refer to during this task).

They were also given the following three instructions concerning activities that they were required to perform during the removal task:

*Ask the experimenter to put "Fragile" notices on the items with glass components (computer, wine rack, television, grandfather clock and microwave) before you move them*

*Allow the removal men access to the bungalow by asking the experimenter to click on the red button beside the clock in the hall at exactly five-minute intervals. You may ask the experimenter to check the time on the clock in the hall whenever you like, but you should not use your watch to check the time.*

*Ask the experimenter to close the door every time you leave the kitchen to keep the cat in.*

Before beginning the task, participants were informed that they should remember to ask the experimenter for a written explanation of the study when they had finished performing the task.

The experimenter first entered the bungalow using the keyboard direction keys. At the clock in the hall, each participant was asked to recall the three additional activities they were required to perform during the removal task (the prospective memory tasks). When the experimenter was confident that each participant could recall the three tasks, and the time on the clock in the hall registered an exact multiple of five, e.g. 10.05, 12.30, the furniture removal task began. The task continued until all the items with "to go" labels had been moved. Participants were then asked to recall the three prospective memory tasks.

Finally, participants were given the prospective memory questionnaire to complete. Where necessary, the experimenter completed the questionnaire in accordance with the participant's responses.

If participants failed to ask for the return of their belongings or for the written explanation of the study, these items were given to them as they left the study room.

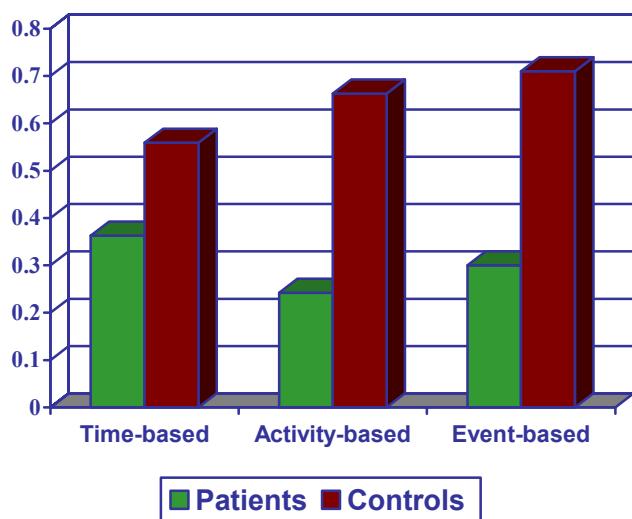
### 3. RESULTS

According to Kvavilashvili and Ellis, 1996, there is a retrospective memory component of remembering to perform actions in the future, that of actually remembering what the action is. Unfortunately, 14 stroke patients and two control participants failed to recall all three of the prospective memory tasks when they were questioned immediately the removal task had finished. Indeed, four stroke patients and one control failed to recall any of these tasks. Since participants who failed to recall *what* actions they were required to perform would obviously forget *when* to perform them, these 16 participants were not included in the following analyses.

In all the statistical analyses the probability level was set at 0.05. There was no significant difference between the remaining 22 stroke patients and 20 controls in terms of age, [Patients' mean 72.95 years, Controls' mean 68.85 years,  $t(40) = 1.58$ ,  $p = 0.12$ ], or years in full-time education, [Patients' mean 10.95 years, Controls' mean 10.9 years,  $t(40) = 0.66$ ,  $p = 0.94$ ].

#### 3.1 VR-based prospective memory tasks

Each VR-based prospective memory task produced 3-6 retrieval occasions. Figure 1 shows the mean probability of stroke patients and controls correctly performing the three VR-based prospective memory tasks.



**Figure 1.** Mean probability of correct performance in the three VR- based prospective memory tasks.

Figure 1 indicates that the performance of the controls was higher than the patients in all three prospective memory tasks. However, there appears to be less difference between patients and controls in the time-based task than in the activity and event-based tasks.

Statistical analyses of the probability of correct completion of each of the VR prospective memory tasks

used a  $2 \times 3$  analysis of variance (ANOVA) with one between-participants' factor (patients vs. controls) and one within-participants' factor (time vs. activity vs. event-based prospective memory task). There was no significant difference between the three prospective memory tasks, [ $F(2,40) = 0.49, p = 0.61$ ], but there was a highly significant difference between the patients and controls, [ $F(1,40) = 19.43, p < 0.001$ ]. There was also a marginally significant interaction between the prospective memory tasks and patients vs. controls [ $F(2,40) = 2.51, p = 0.088$ ].

A simple effects investigation of this marginally significant interaction showed a highly significant difference between patients and controls in the activity-based prospective memory task [ $F(1,40) = 21.63, p < 0.001$ ], and in the event-based task, [ $F(1,40) = 12.72, p = 0.001$ ], but only a marginally significant difference in the time-based task, [ $F(1,40) = 4.00, p = 0.052$ ].

### 3.2 Real-life prospective memory measures

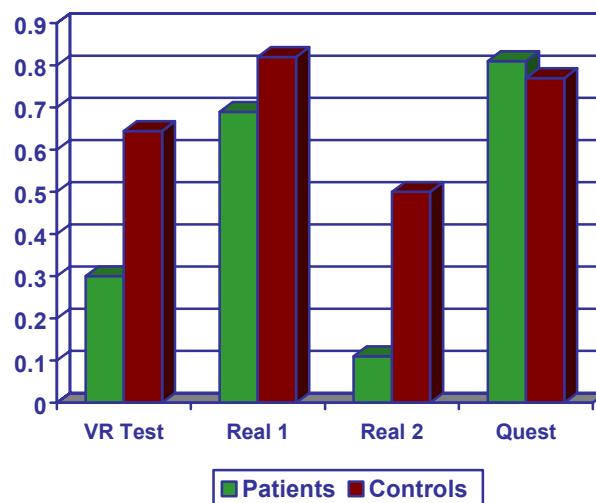
Seventeen of the 22 patients and 16 of the 20 controls remembered to ask for the return of their belonging at the end of the study. Conversely, only three patients and ten controls remembered to ask for a written explanation of the study. Chi-square tests revealed that there was no significant difference between patients and controls remembering to ask for their belongings [ $\chi^2 < 0.001, p = 0.57$ ], but there was a significant difference between patients and controls remembering to ask for a written explanation of the study [ $\chi^2 < 4.89, p = 0.01$ ].

### 3.3 Prospective memory questionnaire

Results of the prospective memory questionnaire indicated that patients rated their own prospective memory abilities as highly as controls [patients' mean = 55.59, controls' mean = 54.37]. An independent t-test confirmed that there was no statistical difference between the patients' and controls' ratings, [ $t(39) = 0.61, p = 0.54$ ]. Interestingly, there was no significant correlation between participants' overall performance in the VR prospective memory test and their scores in the prospective memory questionnaire [Pearson's correlation 0.21,  $p = 0.179$ ].

### 3.4 A comparison of performance across the three different prospective memory measures

Figure 1 highlights the differences between patients' and controls' overall performance in the VR-based prospective memory test (collapsed across the three VR-based prospective memory tasks), their performance in the real prospective memory tasks and their subjective ratings in the prospective memory questionnaire.



**Figure 2.** Performance probabilities in the different prospective memory measures (VR Test = Overall performance in the VR-based prospective memory test; Real 1 = Remembering to request the return of belonging; Real 2 = Remembering to request a written explanation; Quest = Performance in the subjective prospective memory questionnaire).

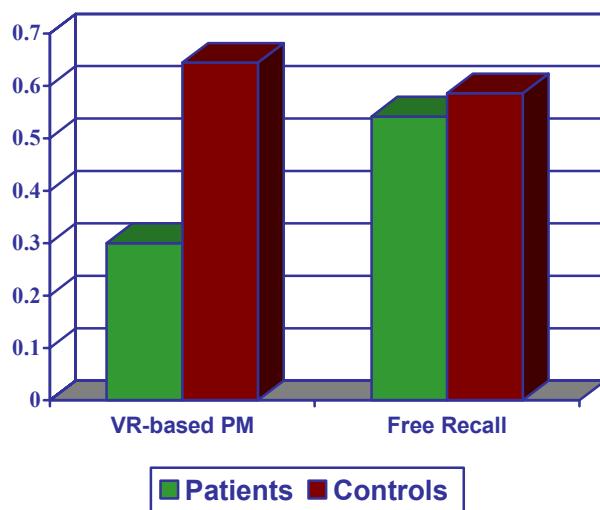
As can be seen from Figure 2, patients were impaired at the VR-based prospective memory test and one real prospective memory task, requesting a written explanation of the study. However, they were not impaired at

the other real task, requesting the return of their belonging. Neither did they subjectively rate their prospective memory as being worse than the controls.

### 3.5 Free recall (ability to recall events in the past)

Mean performance of patients in the free recall test was 6.5 compared to the mean performance of controls which was 7.3. However, an independent t-test found no significant difference between patients and controls in the free recall test, [ $t(40) = 1.42$ ,  $p = 0.16$ ].

Figure 3 compares overall performance probabilities in the VR-based prospective memory test with performance probabilities in the free recall test.



**Figure 3.** Performance probabilities in the VR-based prospective memory test and the free recall test.

As can be seen from Figure 3, patients were more impaired at the prospective memory test than the free recall test whereas the performance of the controls was similar in the two tests. It would therefore appear that stroke patients' prospective memory is more impaired than their retrospective memory, as measured by a free recall test.

## 4. DISCUSSION

In this study, a virtual environment was used to realistically compare the performance of stroke patients and age-matched control participants on event-based, activity-based, and time-based prospective memory retrieval tasks whilst they were performing a furniture removal task. Also included in the study were two measures of real-life prospective memory, a questionnaire relating to participants' subjective ratings of their own prospective memory abilities, and a free recall test.

An important finding that emerged from the study was that 14 of the 36 stroke patients and 2 of the 22 control participants were unable to recall all three of the prospective memory task instructions immediately they had finished the furniture removal task, even though they had been able to recall them immediately prior to beginning the task. If a stroke patient is unable to remember *what* is required, it is highly unlikely that he or she will remember *when* to do it. This is obviously a very real problem and should be borne in mind by therapists during rehabilitation.

The main result from this study was that the remaining stroke patients were impaired at all three prospective memory tasks, but less impaired at the time-based task. This result is counter to Maylor's (1996) prediction regarding the effects of age on prospective memory ability "...that age-related impairments should be more apparent in time-based tasks than in event-based tasks (which contain environmental support in the form of some external cue event)" p.178. This prediction is based on Craik's (1986) theory of age-related decrements in memory which proposes that self-initiated processing becomes more difficult for the elderly. If

self-initiated retrieval is not more difficult for stroke patients, their inability to remember to perform tasks in the future must be attributable to a different impairment, perhaps an inability to multi-task. Alternatively, it is possible that the time-based task (instructing the experimenter to press a button by the clock in the hall at exactly 5-minute intervals) did not represent a realistic time-based task because the interval between each retrieval occasion was too short and stroke patients continually kept the task in consciousness. However, it is unlikely that the control participants adopted this behaviour as their performance in the time-based task was worse than their performance in the two other tasks (See Figure 1). Further research, utilising different time intervals in the time-based task, is required to investigate this effect.

The finding that the stroke patients were not impaired compared to the controls at the real prospective memory task of asking for the return of their property, but they were impaired at asking for a written explanation of the study, indicates how important motivation is in prospective memory performance. If rehabilitation strategies can encourage stroke patients to be more motivated to remember, it follows that their prospective memory abilities would improve.

Another aim of rehabilitation should be to explain to stroke patients that they may be likely to experience difficulties in remembering to perform tasks in the future, particularly as the results of the questionnaire which assessed patients' and controls' subjective knowledge of their own prospective memory abilities indicated that they are not aware of how impaired they are at prospective memory tasks. It is possible, however, that the stroke patients may have been referring back to their pre-stroke behaviour when completing the questionnaire, as some of the questions referred to situations which they would not encounter in a stroke rehabilitation ward.

It would appear from the finding that stroke patients were not significantly impaired at the immediate free recall task but they were impaired at the prospective memory tasks, that prospective memory ability is more affected by stroke than retrospective memory ability. However, the finding that 14 stroke patients failed to recall all three prospective memory instructions indicates that delayed free recall may be more affected by stroke than immediate free recall. Future research should compare stroke patients' immediate and delayed free recall to determine whether stroke patients do have particular problems retaining information during an intervening task.

## 5. CONCLUSIONS

In this study, virtual reality proved a useful medium to test stroke patients' prospective memory ability. The results of this exploratory study indicated that stroke patients have particular problems with both the content and retrieval of prospective memory tasks, i.e. *what* to remember and *when* to remember. However, when they were very motivated, they were able to overcome their impairments. Rehabilitation therapists should also note that stroke patients, may not be aware that they are susceptible to prospective memory problems.

Future studies would benefit from using this testing procedure to investigate whether there is any relationship between the area of the brain affected by stroke and prospective memory ability. If such a relationship were found, future stroke rehabilitation could be more effectively directed towards specific impairments of individual patients.

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# ICDVRAT 2002

## Session X. Virtual Environments for Special Needs

Chair: Penny Standen



# **Finding a place to sit: a preliminary investigation into the effectiveness of virtual environments for social skills training for people with autistic spectrum disorders**

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## **ABSTRACT**

Seven teenagers with an Autistic Spectrum Disorder (ASD) experienced a Single-User Virtual Environment (VE) of a café, with the learning objective of finding a place to sit in different circumstances. Participants also saw a video of real cafés and buses and were asked to choose where they would sit and why. These measures were taken three times: half of the participants received their VE intervention experience between the first and second videos, and the other half received this experience between the second and third measures. Naïve raters coded explanations according to level of social appropriateness. There was a significant improvement in the appropriateness of social observations in the learning of specific objectives in the same café context. Generalisation of learning to a bus context was more difficult and more spontaneous for some individuals than others. Conversations referring to the social scenario depicted by the VE were a great learning opportunity for the participants. This emphasised the importance of the teacher's use of the technology as a teaching tool rather than technology that will directly teach students. The results positively encourage the idea that VR could be a good learning tool for social skills for people with ASD.

## **1. INTRODUCTION**

### *1.1 Why Virtual Reality and Autistic Spectrum Disorder?*

Autistic Spectrum Disorder (ASD) encompasses Autism and Asperger's Syndrome (Wing, 1996). People who come under this umbrella term have difficulties in three main areas (commonly called the Triad of Impairments): communication, imagination, and social skills. The use of Virtual Reality (VR) has been proposed by some (e.g. Parsons & Mitchell, 2002) as potentially offering a platform to teach social skills to people with ASDs. Users of the technology could be able to practise specific skills in a safe, calm environment which enables rule learning and repetition of tasks. Playing different roles within a Virtual Environment (VE) could be beneficial in perspective-taking of others within a social situation, something that people with ASDs struggle to understand easily (Mitchell, 1997). Many people with ASDs enjoy using computers and related technology, have made significant learning gains using different software packages (e.g. Moore & Calvert, 2000), and might welcome them to study aspects of life that they do not find simple.

### *1.2 What do we know already about how people with Autism can use VEs?*

So far, due to the dearth of previous research on the use of VR with people with ASDs, researchers involved in the AS Interactive project at the University of Nottingham (Parsons et al., 2000) have had to answer more fundamental questions about use and understanding before being able to consider whether this technology is suitable for teaching social skills. The emerging picture has been very positive, showing that use of the technology, including abilities using the joystick, mouse and interactions with the VE were akin to normally developing participants matched by Performance IQ (Parsons et al., submitted). Participants also showed a basic understanding of representations, and mostly understood the difference between a videoed scene of a café and a VR café. All participants who took part in previous studies were very motivated by the use of the technology, and commented that they liked using the programs.

### 1.3 The present study

This present study aims to build on the encouraging results obtained so far, by investigating learning of a specific social skill within a VE. The social skill under investigation was to know where to sit in a café in relation to where strangers were sitting. To assess social skills before and after VE use in a real café could be problematic, due to not being able to control variables, for example, how busy it was. Therefore, videos of a real café were used as an approximation of real-world judgements, in order to assess any changes in explanations after using the VE. The main hypothesis was that after using the four progressive levels of the VE, there would be a marked improvement in the appropriateness of participants' social judgements of choice of seating within a café context. In addition, the issue of whether participants would generalise judgements to a different scenario was assessed using video clips of buses.

## 2. METHOD

### 2.1 Participants

7 participants, 4 males and 3 females, were chosen from a special school in the UK for people with ASDs to take part in this study. All were diagnosed with an ASD, and aged between 14 and 16 years (mean=15.0 years). All showed a full-scale IQ between 65 and 110 (mean = 83.1; assessed by the Wechsler Abbreviated Scale of Intelligence; Wechsler, 1999). The mean verbal score (VIQ) was 81.9 (range 55 to 125) and the mean performance score (PIQ) was 87.1 (range 68 to 107). Participants were divided into two groups, broadly matched in terms of IQ, gender and age. No significant differences were found between the characteristics of the two groups using independent samples t-tests. Parental permission was obtained before commencing the study.

### 2.2 Design

This study is a mixed design; all participants received the same tasks, but completed them in a different order (see Table 1).

**Table 1.** Ordering of tasks in the overall study design

Group	Time 1		Time 2		Time 3
1	Video measures	Intervention with VR Café	Video measures	—	Video measures & verbal feedback
2	Video measures	—	Video measures	Intervention with VR Café	Video measures & verbal feedback

### 2.3 Materials

The VEs were built using Superscape VRT and run on a laptop computer or PC using Visualiser software. A joystick and a mouse were used to manoeuvre around the environment and activate objects or initiate interactions within the environment, respectively. The video measures were shown using a combined 14-inch television and video player. All sessions were digitally videotaped for later analysis and transcription, and photos were made through the digital picture capture function. A video with 15 30-second excerpts of cafés and buses in and around Nottingham was created specifically for the video measures.

### 2.4 Procedure

**2.4.1 Use of Virtual Reality Café** All students (except one, P3) had used VEs in previous studies (Parsons et al., submitted). These were: a training environment designed to practice use of the joystick and mouse, carrying out procedural tasks in a small café (such as choosing food and drink and paying) and negotiating around avatars in a Café in order to obtain a drink, designed to assess their awareness of personal space in a VE. P3 used the first 2 out of 3 of these VEs before participating in this study.

The VE under investigation consisted of 4 main learning levels with 3 training levels beforehand. The training levels consisted of teaching the participant about how to click areas for different functions (see Table 2). The learning levels were graded in terms of difficulty (Figures 1 & 2), the higher levels with more avatars in different places to make the task more complex and socially demanding (see Table 2).

For the main learning levels, the participant started at the canteen till with food and drink on a tray, and was told that their task was to "Find a place to sit down" from the choice of six tables. The VE program was designed to give visual and verbal feedback that might encourage the participants to learn where was the best

place to sit in different circumstances. There were two main “rules” that were taught: when there is an empty table available in a café, you should sit there rather than sit with strangers; and when there are not any empty tables, you should ask someone “Can I sit down?” or “Is this seat available?” before sitting down. If someone sat down without asking, the person sitting at the table would say “Excuse me, that seat is taken”. If the participants chose an inappropriate question, “What is your name?”, they were told that this was not connected to their task. All verbal instructions and speech were written in the text box to make it accessible for those who preferred listening or reading. The session was scaffolded by the researcher to reflect participants’ individual needs. There were no specific scripted prompts, that is, questioning where appropriate, letting the participant make “mistakes” when it would open up a learning opportunity, and discussing with the participant what the “most polite” course of action would be in different circumstances. There were two VE sessions for each individual, within 7 days of each other. The first session consisted of the training levels 1 to 3, then teaching levels 1 to 4. The second consisted of teaching levels 1 to 4, to remind them of the different rules in the scenarios. Then the participants completed a worksheet in which they completed the sentences “When a café has at least one empty table, you should...” and “When a café has no empty tables, you should...” accompanied by screenshots of the related VE levels.



**Figure 1. Level 1: Empty café**



**Figure 2. Level 4: Busy Café**

**Table 2. A description of each level of the Café Virtual Environment**

Level	Set-up	Learning objectives
<b>Training 1-3</b>	Listen to instructions and click on areas in the VE corresponding to different functions.	<p>Learn which areas to click in the VE to perform different actions:</p> <ul style="list-style-type: none"> <li>▪ Click on table to sit down</li> <li>▪ Click on floor to stand up</li> <li>▪ Click on ear to rehear the current instruction</li> <li>▪ Click on the question mark to hear the overall task</li> <li>▪ Click on the speech bubble icon to ask a question</li> <li>▪ Choose a question and select OK to ask a person 1 of 3 questions</li> </ul>
<b>1</b> see Fig 1.	All six tables are empty, and there is no-one else in the café standing up.	<ul style="list-style-type: none"> <li>▪ Manoeuvre around the café.</li> <li>▪ Choose a table to sit down at.</li> </ul>
<b>2</b>	2 tables are full, 3 tables have at least one person with some free spaces, and 1 table is empty.	<ul style="list-style-type: none"> <li>▪ Choose an empty table to sit down at</li> <li>▪ Understand where it is alright to sit down without asking anyone.</li> </ul>
<b>3</b>	3 tables are full, and 3 tables have 1, 2 or 3 people sat at them. There are no empty tables.	<ul style="list-style-type: none"> <li>▪ Understand where it is necessary /appropriate to talk to people in a café</li> <li>▪ Understand what is appropriate to say to strangers</li> </ul>
<b>4</b> see Fig 2.	Set-up of tables is exactly the same as level 3. There is background noise of talking and laughing, and some people are walking around the café.	<ul style="list-style-type: none"> <li>▪ Be able to do all of the above with background noise.</li> <li>▪ Cope with and manoeuvre around people walking around</li> </ul>

**2.4.2 Video Measures procedure** All participants were asked to watch videoed scenes at three times. Half of the participants experienced the VE intervention between Time 1 and 2 (Group 1), and half experienced it between Time 2 and 3 (Group 2). Five excerpts (see Table 3) lasting approximately 30 seconds each were shown at each time, and three different sets of these. The order that these three sets were shown was counterbalanced across participants.

**Table 3.** A description of each excerpt from the video

Name	Description	Assessment of learning type
Café A	Café: At least one table with no-one sitting at it	Specific learning
Café B	Café: All tables with at least one person sitting at it	Specific learning
Bus A	Bus: At least one empty double seat	Generalising learning between contexts
Bus B	Bus: All double seats with at least one person	Generalising learning between contexts
Bus C	Bus: Bus Driver seat not inhabited	Over-generalisation of learning

The participants were told that they were going to view a short video of some cafes and buses and would be asked some questions about it. For the cafés, they were told: “When you go into this café, you need to sit down to eat your food”. For the buses, the participants were told: “When you go onto this bus, you need to sit down to travel”. Then after either question, they were asked: “What would you do next?” After providing a description of what they would do (sometimes with further discussion with the researcher), they were asked “Why would you do that?” or “Why would you sit there?” Participants were encouraged to specify exactly where they would sit or stand on the viewed scene by pointing on the television screen, and were digitally videoed during the whole time of the 5 excerpts.

### 3. RESULTS

#### 3.1 Excluded participant

One participant (P1) had to be excluded from further work after his first VE session. He sat down at tables without asking 8 times in total, and did not change this inappropriate behaviour after the program and the researcher gave feedback. He became frustrated that he was not succeeding in the task, so it was decided by a teacher and the researcher to discontinue his work with the VE. This left 6 participants who took part in the whole study, three in each group.

#### 3.2 The VE sessions

**3.2.1 Behaviours shown** Most individuals made inappropriate actions only in the first session (Table 4), or not at all (P3, P5, P6, and P7), which included all 3 females (who were higher in their IQs than the males). The two participants who still made errors on the second session (P2 and P4) were not making the errors that were directly tackled with feedback from the VE (i.e. sitting down without asking), but were making additional actions in approaching people in the café to make contact with them, particularly P4, who had behaved in a similar way in the VEs in a past study (Parsons et al., in preparation).

**Table 4:** Inappropriate Actions in VE sessions

Action	Participant	P2		P3		P4		P5		P6		P7	
		Session	1	2	1	2	1	2	1	2	1	2	1
Sitting down without asking		-	-	2	-	-	-	1	-	2	-	-	-
Asking an inappropriate question		-	-	-	-	2	2	-	-	-	-	-	-
Returning to someone already asked		-	-	2	-	-	-	-	-	1	-	-	-
Asking someone standing up a question		-	-	-	-	3	1	-	-	-	-	-	-
Full table visit with intention to sit or ask a question		1	3	2	-	-	1	-	-	1	-	-	-

**3.2.2 Interactions between facilitator and participant** The role of the facilitator (researcher in this case) was important in making sense of the feedback the VE gave when inappropriate actions were made, more so with some participants than others. Table 5 gives an excerpt from a transcription of a conversation between the researcher (R) and the participant (P4) whilst using the VE to illustrate this point.

In the session with P4, the researcher is enabled by the technology to “look around” the café many times, to point at and discuss individuals in particular. It is possible that P4 may not have understood about the rule to sit at an empty table. However, on the worksheet after the second VE session, his completion of the first sentence was “When a café has at least one empty table, *you should go and sit at it*” indicating that he *did* know which table he should sit at, but just wanted to explore the café and the people. P4 made many advances towards talking to people standing up and sitting at full tables in previous studies, which are behaviours that he might not have attempted in ordinary life.

**Table 5:** Transcript of interaction between researcher and participant

VE Session 2, Level 2: Empty table available
P4 goes to tables with people sitting at them rather than sitting on the empty table. R resets level in order to have a discussion about the level
<b>R:</b> <i>Where would be the best place to sit down? You can't sit on that one, or that one</i> (pointing to full tables). <i>There's three tables with some free seats but there's one table with <u>all</u> free seats. Where do you think is the best place to sit?</i>
(P4 points at a 4-seat table with a couple sitting at it)
<b>R:</b> <i>Why?</i>
<b>P4:</b> <i>Because these people sound friendly</i>
<b>R:</b> <i>They sound friendly. But if this was a café and you didn't know anybody...</i>
<b>P4:</b> <i>Just ask them if I could sit down there</i>
<b>R:</b> <i>Would it not be best to go to the empty table? These two people (pointing to couple) might be having a conversation that was quite... private.</i>
(No response)
<b>R:</b> <i>Do you think they might just want to chat? Maybe they're on a date and they just want to talk to each other.</i>
(No response)
<b>R:</b> <i>Do you think maybe it would be best to go to the empty table?</i>
<b>P4:</b> <i>To the red one? No way!</i>
<b>R:</b> <i>Why not?</i>
<b>P4:</b> <i>I'd be all on my own</i>
<b>R:</b> <i>You don't want to be by yourself?</i>
<b>P4:</b> <i>No</i>
<b>R:</b> <i>But what about these people? They may just want to be by themselves and be quiet. Do you think you might be disturbing them?</i>
(No response)
Asks "What is your name?" to the table with a couple. He is told "That is not connected to your task. Try something else"
<b>R:</b> <i>They didn't really like that did they?</i>
Asks "Can I sit down?" to the table with a couple. He is told "Sorry, someone is sitting there"
<b>R:</b> <i>I think you should try the empty table as then you wouldn't have to ask anybody would you?</i>
Asks "Is this seat available?" to the table with a couple. He is told "Sorry, someone is sitting there"
Asks "Is this seat available?" to the table with a man. He is told "Sorry, someone is sitting there"
<b>R:</b> <i>Why don't you go to the empty table? 'Cause you know no-one's sitting there, don't you?</i>
Goes to empty table and sits down

### 3.2 Video judgements

The performance on this task was assessed using the judgements of 10 naïve independent raters (age range 20 to 51 years; mean=29; 1:1 sex ratio), most of whom were students. The 95 excerpts were randomly ordered into a questionnaire format, with the dialogue between the researcher and participant shown and the digital picture of the specific café/bus talked about, with an arrow indicating where the participant had chosen to sit (see Figure 3 for an example). No information was given about participants' background or diagnosis, or the nature of the study.

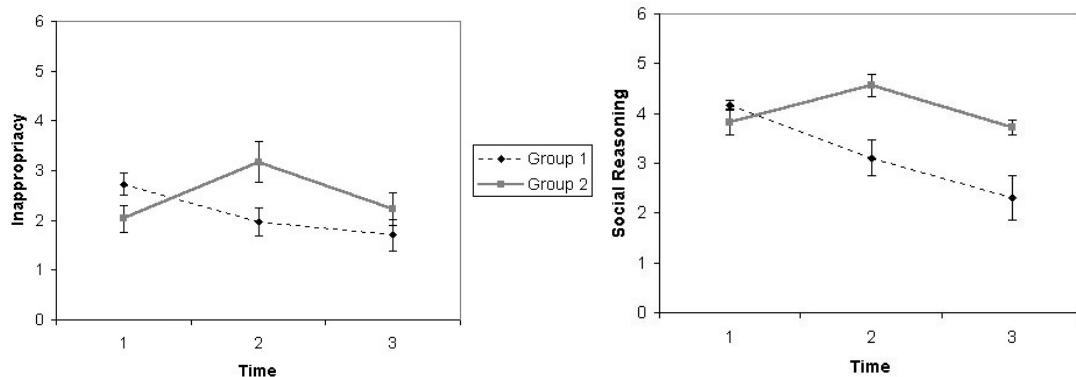


**Figure 3.** An example of where a participant would sit in a bus, and the dialogue with the researcher, in the same format as given to the raters.

Raters were asked to rate this information on two scales in response to two questions. Firstly: "How socially appropriate was their decided action?" This was rated on a 6-point scale from "Ideal" (1) to "Inappropriate" (6). If it was rated inappropriate, they described the nature of this by choosing "Too Polite" or "Rude". The second question to raters was "How social was their reasoning or explanation behind the action?" Raters were asked to indicate on a 6-point scale from "Not at all social" (1) to "Very social" (6).

**3.2.1 Specific Learning.** Gains in understanding were hypothesised to happen only after the different groups' experience with the Café VE. Thus for Group 1, an improvement was expected to happen between Time 1 and 2, yet Group 2 would not improve until Time 3, after they had used the VE. Participants in both groups were able to learn from the two specific learning objectives that were focussed on in the VE sessions, as shown by independent ratings of the video judgements over the three measures.

For the scenario with at least one empty table (Café A), participants were generally rated as showing more ideal behaviour after using the Café VE (Figure 4), as supported by the t-tests showing an improvement between Time 1 and 2 for Group 1 and Time 2 and 3 for Group 2 (Table 6). A repeated measures ANOVA showed that Time was a significant main effect ( $F(2,18)=7.5$ ,  $p<0.01$ ), as was Group ( $F(1,9)=12.07$ ,  $p<0.01$ ) and also the interaction between Time and Group ( $F(2,18)=8.541$ ,  $p<0.01$ ). Initial ratings of this variable were quite low at Time 1, possibly indicating that the students knew what they should do in this situation already. Some students might not have necessarily needed to be taught the learning objective that "You should sit at an empty table if there is one available"; which is why large gains were not made in this variable.



**Figures 4 & 5:** Café A, the café with at least one empty table available: Inappropriacy and Social Reasoning mean rating scores for Groups 1 and 2 over the measures at three times.

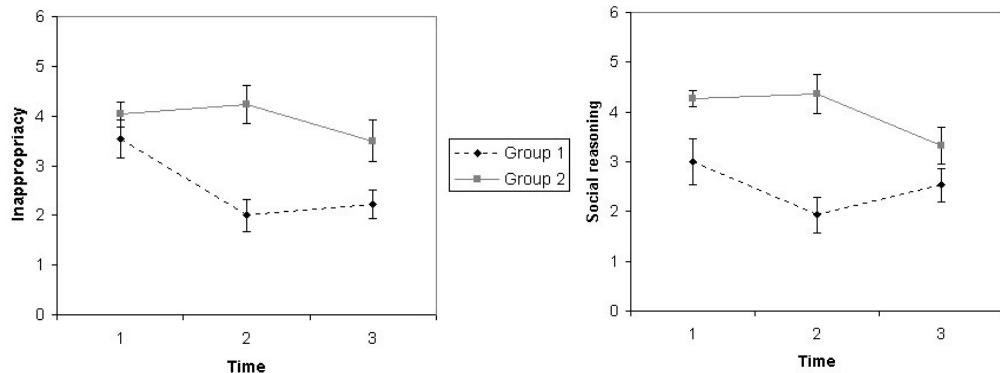
The VE use also made an impact on the social reasoning assessment, also more within Group 1 (see Figure 5), with significant improvements made over the time that they used the VE (Table 6). The ANOVA showed that there was a significant main effect of Time ( $F(2,18)=7.5$ ,  $p<0.01$ ), Group ( $F(1,9)=12.07$ ,  $p<0.01$ ) and an interaction between Time and Group ( $F(2,18)=8.541$ ,  $p<0.01$ ). There were differences at Time 2 between groups, but also at Time 3, indicating that possibly Group 1 were made more aware to the social reasons behind behaviour in a café through the VE sessions than Group 2.

**Table 6:** Café A: mean differences and matched pairs T-tests showing differences and improvements.

Difference	Inappropriacy		Social Reasoning	
	Mean difference	T-test (df=9)	Mean difference	T-test (df=9)
Time 1: Between groups	<b>0.70</b>	<b>3.706**</b>	0.33	1.061
Time 2: Between groups	<b>-1.20</b>	<b>-3.375**</b>	<b>-1.47</b>	<b>-4.047**</b>
Time 3: Between groups	-.53	-1.922	<b>-1.43</b>	<b>-3.204*</b>
Group 1: Difference between Time 1&2	<b>-0.77</b>	<b>-3.083*</b>	<b>-1.07</b>	<b>-2.569*</b>
Group 1: Difference between Time 2&3	-0.27	-0.967	<b>-0.80</b>	<b>-2.882*</b>
Group 2: Difference between Time 1&2	<b>1.13</b>	<b>4.221**</b>	<b>0.73</b>	<b>2.339*</b>
Group 2: Difference between Time 2&3	<b>-0.93</b>	<b>-3.280**</b>	<b>-0.83</b>	<b>-3.049*</b>

\*= $p<0.05$  \*\*= $p<0.01$

The perceived inappropriateness of behaviour decreased considerably for both groups over time in relation to use with the VE (Figure 6). There was a significant difference between the groups at time 2 (Table 7), and both groups decreased in the Inappropriacy scale during the time when they used the VE, although not significantly so for Group 2. This is reflected in the repeated measures ANOVA which revealed that Time was a significant main effect ( $F(2,18)=5.408$ ,  $p<0.05$ ), Group however was not ( $F(1,9)=4.438$ ,  $p=n.s.$ ) but there was a strong interaction between Time and Group ( $F(2,18)=11.694$ ,  $p<0.001$ ). In their post-intervention video measures, all participants were able to say that they should ask people sitting at a table whether the seat was available before sitting down, whereas before the VE use, none of them said they would do this. This observation was independently supported by the judgements of the naïve raters.



**Figures 6 & 7 : Café B, the café scenario with no empty tables available: Inappropriacy and Social Reasoning mean rating scores for Groups 1 and 2 over the measures at three times.**

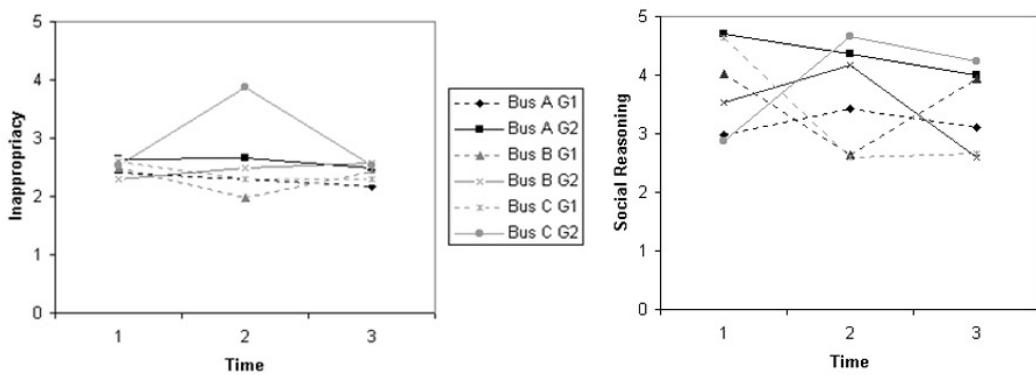
Social Reasoning followed a similar pattern across time (Figure 7), and the groups only improved in this scale during the time that they used the VE (Table 7). The ANOVA revealed that Time was a significant main effect ( $F(2,18)=7.203$ ,  $p<0.01$ ) as was Group ( $F(1,9)=28.256$ ,  $p<0.001$ ), and the Time and Group interaction ( $F(2,18)=3.919$ ,  $p<0.05$ ).

**Table 7: Café B: mean differences and matched pairs T-tests showing differences and improvements.**

Difference	Inappropriacy		Social Reasoning	
	Mean difference	T-test (df=9)	Mean difference	T-test (df=9)
Time 1: Between groups	0.5	1.296	1.27	3.167*
Time 2: Between groups	2.23	5.800***	2.43	4.245**
Time 3: Between groups	1.27	3.191*	0.8	2.395*
Group 1: Difference between Time 1&2	-1.53	-7.042***	-1.07	3.403**
Group 1: Difference between Time 2&3	0.23	0.920	0.6	-1.890
Group 2: Difference between Time 1&2	0.2	0.580	0	-.269
Group 2: Difference between Time 2&3	-0.73	-1.754	-1.03	2.514*

\*= $p<0.05$  \*\*= $p<0.01$  \*\*\*= $p<0.001$

**3.2.2 Generalised and over-generalised learning** The participants did not seem to generalise social skills learnt from the café to apply them to the bus scenarios (Figure 8), nor were they made more aware of the social reasons why people sit where they do when they board a bus (Figure 9). The absence of a clear pattern from the graphs shown is supported by the lack of statistically significant differences and interactions. The bus video with the bus driver's seat available was the only variable to show an effect in an ANOVA: the Time and Group interaction being a significant main effect ( $F(2,18)=8.2$ ,  $p<0.001$ ). However, this interaction was possibly due to the anomaly of P6's statement at Time 2 (Group 2; before VE use) that he would sit in the driver's seat, and thus was judged by raters to be inappropriate behaviour. Thus it could be safely concluded that VE learning is specific to that particular scenario and users do not spontaneously apply learning to other similar scenarios.



**Figures 8 & 9 : Buses A, B & C, scenarios corresponding to the caf  s and with a bus driver's seat free: Inappropriacy and Social Reasoning mean rating scores for Groups 1 and 2 over the measures at three times.**

## 4. DISCUSSION

### 4.1 People with ASDs can use VR technology and can respond to feedback

Most students (all apart from P1) were happily able to learn the appropriate responses through the interactivity with the VE, and did not have difficulty in coping with the negative feedback that an inappropriate behaviour initiated. Their ease of use of the technology was not a surprise considering their previous use of VEs. However, the novel outcome was that they listened to the advice of the researcher and the responses programmed within the VE, and did not continue to make errors which the program was directly tackling. Neale et al. (2002) have extended this knowledge of how VEs can be incorporated into social skills teaching, by investigating how a teacher can use it in variable ways, for example through initiating whole-class discussions over different actions in a VE.

### 4.2 Social skills learning is carried over to another medium, but not to another context

The video measures over time suggest an improvement in social judgements in most students after using the VE caf   for caf  s with empty tables (A) and without (B). The rated improvement coincided with the timing of the intervention, giving strong evidence that it was the VE use that caused the change in judgements. Given the low inappropriacy rating before VE use, improvements made with Caf   A were not so noticeable, but Caf   B judgements improved considerably after VE use, showing that this was something that they needed to learn. Some students did show some crossover between contexts, but generally the learning done in this study was context-specific, although it cannot be determined from this study whether students could generalise to other domains if asked to do so specifically. Awareness of social reasons of why they might do something in a certain situation improved also, showing that it is not just the mechanics that they are learning about social skills in the VE but the reasons behind them also. Further work presently being carried out is looking further into learning within VEs, and whether social skills can be displayed in real-world contexts after training in a VE.

### 4.3 VE social skills training has unique capabilities in comparison with in-situ teaching

This study has shown the potential for social skills teaching and learning, being a "safe" calm alternative to *in situ* social skills training. The participant is not only greeted with the verbal and visual feedback from the VE, but this is translated and mediated by the encouragement and teaching from the facilitator, who knows the individual and their own learning style, capability and needs. Moreover, VR can essentially have distinctive advantages over "real-world" social skills training, in enabling rich discussions about socially appropriate actions to take place real-time in reference to the avatars in the VE. Conversations with regard to the "people" in the VE can be done openly, yet in a public caf  , a teacher could not stop in the middle of a caf   with a student and discuss possible actions and their consequences. VR provides a platform in which social situations can be talked about, which has an element of reality. Future studies might reveal what aspect of the VE lessons are the most influential in learning social skills, for example whether it serves as a platform for discussion, it provides unique feedback in the program or something else. This study indicates the potential for social skills training using VR, and creates a sense of optimism for using this technology with people with ASDs to help them make socially appropriate choices.

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# Exploring the role of virtual environments in the special needs classroom

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## ABSTRACT

A series of Virtual Environments (VEs), specifically designed to allow adolescents and adults with high-functioning autism and Asperger Syndrome to practice social skills, have been trialled in a school for students with autistic spectrum disorders. We have taken a qualitative approach to exploring how these programmes might be used to augment traditional teaching practices in a real school. By configuring the VR hardware in different ways and using the programs with various student-teacher combinations we have been able to observe how the VEs are used and to make recommendations as to how they may be modified so they better support teachers and students needs.

## 1. INTRODUCTION

The AS Interactive project has developed a series of Virtual Environments (VEs) with an ultimate aim of using them to support social skills teaching for people with autistic spectrum disorders (ASDs) (Parsons et al., 2000). We are primarily focusing on adolescents and adults at the high-functioning end of this spectrum, with high-functioning autism (HFA) and Asperger Syndrome (AS) who have the core autistic deficits in their social, communicative and imaginative abilities (Wing, 1996), yet have no additional learning disabilities. Although they may manage to cope well with many aspects of everyday life, significant impairments in social understanding may lead to exclusion from many aspects of society.

Difficulties are faced in trying to *teach* social skills, something that the rest of us pick up from our everyday real world experiences and generalise from one situation to another, meaning that there are few existing materials available for teaching these skills. As VEs have been shown to be successful for teaching spatial skills (Stanton, 1998) and procedural skills (Cobb, Neale, & Reynolds, 1998; Mendoza et al., 2000) the AS Interactive project aims to explore what role VEs may take in social skills training.

VR is considered to have great potential as an educational tool and has been judged to be an excellent medium for implicit experiential learning, yet caution has been expressed as to how this style of learning might impact on the conceptual understanding and memory of its users (Machamer & Osbeck, 2000). This has led to the recommendation that VEs should be designed to include breaks of presence, so that the learner might reflect on what they have just learnt (Fencott, 1999; Waterworth & Waterworth, 2000; Whitelock & Jelfs, 1999) or that VEs should be implemented alongside more traditional methods to facilitate the conceptual learning (Bowman, Hodges, Allison, & Wineman, 1999; Crosier, 2000).

We agree with this view, and believe that VEs will only foster learning if used in combination with existing teaching methods, drawing on the strengths of both; it is therefore necessary to examine how these environments can be used in real training situations. We can then use data gathered from these settings to modify VEs so that they better meet user needs.

We suspect that the effectiveness of VEs in teaching people with ASDs will be as a tool to engage the user in a realistic active learning environment and as a motivating visual prop used to focus the attentions of a group of users on a specific social skills issue. The following sections describe our approach to introducing VEs for teaching social skills into a special needs school, our observations from this, and recommendations for VE design modifications to address the needs arising from real training situations.

## 2. OBSERVING VE USE IN SCHOOLS

### 2.1 Aims and objectives

We have examined the use of two VEs in a school for students with ASDs. The overall objective was to enable the teachers to use the VEs in different ways, with various hardware and software configurations, in order to examine how teachers may support VE use and conceptual understanding and to identify how the VE might be improved to better support these reflective practices. Alongside this was the ongoing collection of information about the utility and usability of the programs, which allowed regular modifications and improvements to be made.

### 2.2 Learning environments

Our intended end-user group are adolescents and adults and we understand that these VEs would be primarily used in 'social groups', schools and colleges. To ensure that the VEs developed are appropriate for these user populations an iterative process of 'user-centred design' is being conducted. This approach has been careful to consider user characteristics and requirements as well as the needs of teachers and autism-training professionals (Neale, Cobb, & Wilson, 2002).

VEs have been developed that allow the practise of social skills in a café and a bus, both of which have various levels of social difficulty. In both the Café and Bus VEs (see figure 1) the user needs to find an appropriate place to sit. A more detailed description of these environments can be found elsewhere (Cobb et al., 2002).



**Figure 1.** Screen-shots of the Café and Bus VEs. The user must find somewhere to sit.

### 2.3 Participants

We worked with a group of 16-19 year olds and their teachers and teaching assistants at a school for students with ASDs. All 8 students in the class have ASDs, and we included all of them in group activities, but worked mainly with the 3 higher functioning students for individual activities. As we had worked periodically with the class over 18 months and more intensively over 2 months, the students knew the researchers well and were used to us being in class and using video cameras, taking very little notice of this.

### 2.4 Methodological approach

An ethnographic style of enquiry was adopted as we wanted to capture a realistic picture of how VEs might be used in real school contexts. VEs were introduced within the classroom and the teachers were given free reign as to how to use them. Researchers were on hand to provide technical assistance only. We wanted to see how professional educators would utilise the technical tools provided in order for the VE developers to tailor the specific VEs so that they better met the teachers' needs. We also wanted to gain a greater general understanding of the potential of these technologies for teaching. The physical setup of the equipment as well as classroom management practices, were of real interest to us, in terms of how they impacted on technology use and learning. All of the sessions described were video recorded and analysed qualitatively. When possible, this information was supplemented by teacher interviews. More structured studies, focusing on effectiveness were also carried out within the project and are described within these proceedings (Leonard, Mitchell, & Parsons, 2002).

In order for the VEs to be applied most effectively in the classroom we have found from previous studies that it is important to familiarise teachers with the technology and research objectives (Cobb, Neale, Crosier, & Wilson, 2001). This was done by holding a teacher meeting where the aims of this evaluation were explained, VEs were demonstrated and used by the teachers, then informally reviewed. Individual teachers

who agreed to participate in the evaluation were then offered additional time to practise using the VEs whilst supported by one of the researchers.

### 3. OUTCOMES

#### 3.1 Observation of VE use

We found that the VEs could support teaching in different ways within the classroom depending on the computer hardware used, familiarity with the VE program, the teacher present, and the number of students present. We observed three main approaches to VE supported learning and have categorised them as: individual tuition, group exploration and group reflection. Descriptions of VE use within each of these categories are below.

**Individual Tuition:** The first couple of times that the VEs were used in school was on a single PC where a student would work alongside their teacher who provided assistance and guidance as necessary. This more ‘traditional’ form of computer use assisted in gauging the suitability of the program for individual students, and identifying their level of understanding. Three students with HFA/AS used the VE.

We observed that the Café VE seemed to be pitched at a suitable level of difficulty for the students, as they could all complete the lower level tasks without assistance (e.g. ‘find a seat in an empty café’) but when it came to the more socially challenging tasks they required more help. Level 3 of the program presents the user with a café at which every table has some people sat at it and the task is to find somewhere to sit down. The students had been taught not to sit down next to someone they don’t know if there is somewhere else to sit, yet they had not discussed with their teachers what the most appropriate course of action might be if there are no alternative places to sit. This meant that they often had to discuss with their teacher the most appropriate strategy for finding a seat. ‘J’ searched thoroughly through the café trying to find an empty table. At a number of tables the computer asked “*Sat at the table is someone you don’t know. What should you do?*” and he responded by backing away, verbalising “*No*” and searching for a better place to sit. Only with further explanation and prompting from his teacher did ‘J’ attempt to ‘speak’ to one of the people sat at a table to ask if he could sit there.

The session outlined a number of ways in which the Café VE could be re-structured to better support learning. One such suggestion, made after observing the students struggle with the most difficult levels of the program, was to introduce an intermediate level that would allow the user to be more gradually introduced to the task of asking a question in the VE. In the program used, when the user first attempts to ask a question (to ask if they can sit down), a negative answer is always given (such as “someone is already sitting there”) and they have to ask a question again before they are successful (this was intended to show the users why it is important that they ask before sitting down). Receiving a negative response to a new action appeared to make some students anxious. An intermediate level may state explicitly that all of the tables in the café had people sat at them, and the task itself could be made marginally easier, if they took the correct approach to solving this problem (i.e. by asking a question) then their attempts would be immediately rewarded.

A week after this session, the Café VE was again used in the same manner, however, many different issues arose from the use of the VEs. By the end of session 1 the students had all successfully completed the highest level of achievement within the Café VE. During session 2 their behaviours were noticeably different. All three of these users had learnt, from the previous session, *exactly* what they needed to do in the VE in order to reach a successful outcome. In this session they displayed repeated behaviours at each of the levels, for example, by visiting the same tables in the same order on each visit to the café, and always making the same choices when they needed to ask a question. It was clear that for each level of difficulty in the Café VE they had visually memorised the environment. For example, in level 2 there is an empty table in the corner of the room where the user may sit and in level 3 there are no empty tables. In level 3, many of the users did not even look around the room to see if they could find an empty table as they had remembered from the week before that in this level there were none.

During this session the users completed tasks within the Café VE much more quickly than they had the week before, and there were far fewer examples of dialogue about the social aspects of the decisions made between them and their teacher. In fact it seemed that most of the decisions that were made were copied from their successful actions made the week before and the social implications of these were not reflected upon.

The behaviours observed during this session have highlighted to us just how adept individuals with ASDs are at learning the ‘correct’ answer to a problem and then repeating it again and again. The importance of programming flexibility within an educational VE has also been exemplified in our observations of the users rote repetition of responses to situations within the VE. Although we made a concerted attempt to introduce flexibility into the VEs throughout the design process we tended to focus on developing a VE that allowed each user to behave differently within it each time it was used. For example there are a number of distinct paths a user may take that would lead to a ‘successful’ or an ‘unsuccessful’ outcome. However, what we did not explicitly consider was the need to force the user to behave differently each time they use the Café VE, or each time they visit the same difficulty level in the VE. Our observations from this session indicated a need to introduce much more randomness within the system, perhaps by presenting the user with a number of VEs that are at least different in some superficial way. For example, changing the look of the café and the people within it, and changing the location of the tables with free spaces should ensure that on each visit the user will be forced to have a look around the café to find the most socially appropriate place to sit. Another approach might be to change the manner in which questions are chosen. When asking a question within the current Café VE it is possible (and quicker) if the user does not re-select a different question each time, but leaves the question selected upon the question that was asked the last time the VE was used. Ensuring that the user has to actively select a question each time one needs to be asked, and changing the questions that are available to them should mean that they have to think about which choice would be the most socially appropriate on each occasion this function is used.

**Group exploration:** The third session aimed to find out how the VEs might be used in a group situation and how teachers may structure this experience. We wanted to explore group use of the VEs, as many of the existing teaching methods used with this class are group-based and the 16+ classroom is arranged so that sofas and chairs face the corner of the room, where a flip chart is usually placed. For this session a laptop was used to run the VEs and they were displayed on a projection screen which replaced the flip chart. One teacher and three classroom assistants were present with eight students. This set up is shown in Figure 2.



**Figure 2.** Classroom setup for group use of VEs.

At first the teacher navigated around the VE and the decisions he took were informed by the suggestions offered by members of the group. An excerpt of dialogue is shown in Table 1, showing that the teacher used the VE to focus on specific social issues and the students could engage in this.

Another example of class discussion of VE use is shown in table 2. It seems clear from the dialogue that class discussion around the interaction with the VE adds richness and meaning to the scene and enables the teachers to explain if something is not clear (for example when the man in the VE says that “someone is sitting there” when no one is literally sitting in the seat).

Each of the students then took turns in using the VE. When students experienced difficulties, for example, when “tricky decisions” needed to be made, these were discussed and influenced by the class as a whole. However, when the students knew what to do in the VE the situation was much different. This type of VE use was characterised by individuals working quickly through the VE making their decisions immediately and leaving little time for the rest of the group to contribute or comment. The teacher tried to involve other members of the group in decisions but the student in control often carried on with what they

were doing and were not influenced by the group discussion that might have been taking place around their actions.

**Table 1.** Dialogue between teachers and students whilst using the Café VE in a group.

Person	Dialogue	Actions
T	Right over in the corner	Navigating towards a table
T	Careful with that tray	
T		Reaches the table
T	Oh in the corner there	
S	Not that one	
T	Which one?	Navigates round to the side
S	There	Pointing
T	Right, that one. You want that table do you?	Navigates up close to the table
VE	Sat at the table is someone you don't know. What should you do?	
S1	Ignore him	
S2	Click on the speech bubble	
S3	Ignore him	
C1	That man is already sitting at the table so it is like his table	
C2	Hang on, S2 is telling us	
S2	Click on that button on the right, T.	

T = teacher; C1 & C2 = classroom assistants; S1, S2, & S3 = students; VE = pre-programmed responses from the VE.

**Table 2.** Discussions around actions in VE.

Person	Dialogue	Actions
T	R: Right, we've chosen that one look, we've chosen that one, 'is this seat available?', 'OK'.	Clicks on OK
VE	No, sorry. Someone is sitting there.	
S1	They're wrong.	
C1	What does that mean then?	
T	Well there is nobody sat there, is there?	Points to screen
C1	Well perhaps, somebody must have gone to the toilet, or...	
C2	Yes, or perhaps that man's sitting at the table, and they've gone to get the food.	
C1	Find another table	
T	Right, OK then, so we won't hang about. We'll go and find another table. Do you think?	
C1	I think that's an excellent idea because that man obviously doesn't want us to sit there.	

T = teacher; C1 & C2 = classroom assistants; S1 = student; VE = pre-programmed responses from the VE.

When discussing this session with the teachers they commented that so much was going on and so many issues were being presented that it was difficult to be able to reflect on them and perhaps discuss why they may have occurred. We observed that this was particularly difficult when a student was in control of the VE as they would interact with the VE at their own pace and find it difficult to inhibit their responses (i.e. stop interacting with the VE) to join in a discussion about what had just happened.

**Group reflection:** The third session of VE use also involved a group working around a projected display, but a different teacher led the activity and a distinctive style of interaction was observed.

At the start of the session, before using the VE, the teacher initiated a group discussion about visiting a café and finding a table - an activity that some of the students had carried out that morning in a real café. The students then took turns to use the Café and Bus VEs. At many points during the session the teacher would

reflect on the behaviours that had taken place in the VE and asked the students questions about this. An example can be seen in table 2 where student 1 is trying to find somewhere to sit in the Café VE.

**Table 3.** Dialogue between teacher and students, reflecting on VE use.

Person	Dialogue	Actions
S1		Needs to sit down, and uses the question "is this seat free?" to ask if he can sit at a particular table.
T	Well done S1	
S1	That's a bit of a funny thing to say "is this seat free?"	
	What does that mean?	
S2	Available	
T	Ohh so it doesn't mean that this seat is not going to cost me any money then. Does it?	
S1,2,3 &4	No!	
T	Well I thought if something was free it meant that you didn't have to pay for it. What does it mean S2? Tell me again what it means.	
S2	Is this seat available?	
T	Right, so it means you can sit on it.	

T = teacher; S1, S2, S3 & S4 = students.

It is clear that the teacher makes a lot of effort to reflect on what has just happened in the VE and discuss the task to clarify some of the issues that are more difficult to understand. It is best if the VE is not being used when this discussion is happening and the teacher usually managed this by moving the student who has just used the VE away from the computer and back to their seat. This limited when discussions could take place as they occurred most successfully at the end of each student's 'turn' on the VE.

On a number of occasions the teacher used the VE to provoke a discussion about other social or behavioural issues relevant to that context that were not directly covered by tasks within the VE. For example, not bumping into people in the café when carrying your tray (see example in table 3) and what to do on the bus if there are no seats at all to choose from. This demonstrates the potential of this technology to support direct and indirect learning aims by providing a set of scenarios or contexts around which the teacher can promote discussion of many social issues.

**Table 4** Teacher promotes discussion about related social issues in a cafe

Person	Dialogue
T	Can I just ask everybody, because student 5, you need a little bit of help with this. If you are trying to find somewhere to sit and you're carrying your tray and there are lots of people around, what have you got to be careful about? What not to do?
S5	Not to bump into people
T	Not to bump into people, that's right. So you have to be thinking about where everybody else is in the café don't you.
Class	Yes

T = teacher; S5 = student; Class = all students

We observed the students frequently trying to sit on the back seat of the Bus VE. As we had not anticipated this behaviour, the levels that we presumed would be difficult to complete were easily completed, as any socially challenging situations had been pre-programmed into the front seats of the bus. This observation highlights the need for the VE to be tailored to the needs of individual students.

One proposal is to modify the virtual bus to make it a more challenging social environment by allowing the teacher to select which seats in the bus are to be occupied and which empty before it is used by an individual. This may allow the VE to train the individual to inhibit a rigid and potentially socially inappropriate behaviour that the teacher is aware of by exploring the consequences of this behaviour in a number of similar situations.

When discussing the use of VEs for social skills teaching the teacher emphasised the difficulty she faces in getting the students to understand the perspectives of others. She identified the potential of VEs in allowing the students to take others perspectives, by role taking within VEs and playing out different scenarios.

### 3.2 Recommendations for VE changes

During this period of observation a number of recommendations were made for changes to be made to the VEs, based on issues that had arisen from VE use in a real school context. These recommendations are listed below:

- The stages needed to progress more gradually as complexity increases and new concepts are introduced. This should reduce anxiety of users who are unsure of what action to take or who carry out an incorrect action in the VE
- The scenarios should be presented in a visually distinctive manner each time the VE is used to decrease rote learning based on the visual presentation of the environment.
- Ensure that each time a new question is asked the user must actively select it and not rely on a default selection, which allows the student to use the same question each time. Different question options would also make this activity more flexible.
- Allow the teacher to tailor the VE to cater for individuals, for example, the teachers could pre-select where people are sat on the bus.
- To enable more effective reflection on group use of VEs facilitate a 'pause' button to be operated by the teacher. This can be used to stop the VE at relevant moments to enable discussion around the social issues encountered.
- Understanding of social understanding involves the consideration of other people's perspectives. Enable the user to find out 'what the other person is *thinking*' in the VE if socially inappropriate actions are taken.

These changes will be incorporated into the VEs and subject to further school based reviews.

## 4. CONCLUSIONS

Our observations from working with these groups have emphasised the need for the designers of education/training VEs to work closely with the 'experts' in this field, be they teachers, training practitioners or classroom assistants. This approach to evaluation has been an effective way to explore the potential of VR as a teaching tool, and a resource to inform the design process so that VR based materials support and supplement existing teaching methods. By working over a series of months with the same school the teachers became familiar with the technologies and were encouraged to direct the way in which the VEs were used. As they grew more confident with using the technologies, they could better identify how the VEs may support teaching and learning. They came up with increasing numbers of suggestions and put them into practice in the classroom.

This holistic style of enquiry is essential when designing and evaluating educational technologies. We believe that VEs for social skills education will be most effective if used alongside other methods. It is therefore necessary to examine how VEs may be used in conjunction with existing teaching practice and tailor their design so that they complement these techniques.

The study identified a series of design modifications which need to be made to improve the suitability of these VEs for use in schools. They include changing the structure of the learning task presented (by making more gradual the presentation of increasingly complex tasks) and designing VEs that enable the teachers to individualise them to address specific learning needs (deciding which seats on the bus are full and allowing them to pause the VE to promote discussion and reflection). The changes should also force the users to make more socially based decisions, rather than replicating their previous actions (i.e. they have to actively select a new question each time and are presented with a different visual representation of the scenario on each visit to the Café VE). We also hope that, by including a function that allows users to visualise other people's thoughts and feelings, we can increase levels of social understanding amongst users.

In addition, this study has highlighted the potential of VEs in setting the scene for teaching a wider array of social scenarios than have been pre-programmed into the environment. In one of the group sessions

observed the teacher would set the scene using the VE and then pose her own additional social scenarios. This may be an especially useful feature of VEs for teaching people with autism as they classically have a very poor imagination and VEs may help users to visualise themselves in a situation.

Further work is continuing with the cyclical process of review and re-development of the VEs. We are also involving the teachers in the production of an activity manual (containing computer-based and classroom-based tasks) to be provided as a resource guide with the final virtual environment training program.

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# **Virtual environment for assessment of rehabilitation equipment**

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## **ABSTRACT**

Selection of assistive equipment for use in the home can be difficult. In many cases a variety of alternative designs may be available and it can be hard to determine the most appropriate one to select for a particular patient. The Derby Disability Equipment Assessment Centre (DEAC) provides a needs-led evaluation programme for the assessment of assistive equipment designed for older people and people with disabilities. The primary criteria for each equipment evaluation vary for each project, but often include safety, ease of use, aesthetics and ease of cleaning, as appropriate. DEAC consider the views of the people who use the equipment to be an essential aspect of product evaluation, however, it is not always practicable to have patient representatives visiting the hospital to review alternative product designs. Taking a variety of products to users' homes for assessment can also be problematic from the point of view of manual handling, set up and travel for therapists. Visualisation in a virtual environment presenting raiser combinations with different furniture was proposed to as a potential alternative, speeding up the assessment process and minimising manual handling risks. A feasibility study was conducted jointly between DEAC and the Virtual Reality Applications Research Team (VIRART) at the University of Nottingham to evaluate the effectiveness of a VE as a tool for rehabilitation equipment assessment, taking into account usability and acceptance of the tool by rehabilitation therapists and disabled or older people. This paper presents the findings from a case study example of a chair raiser evaluation and a comparison of results in product selection preferences between real and VE viewing conditions.

## **1. INTRODUCTION**

The Derby Disability Equipment Assessment Centre (DEAC) at the Southern Derbyshire Acute Hospitals NHS Trust, Derby, UK is one of three centres in the UK evaluating equipment for the Medical Devices Agency (MDA) on behalf of the National Health Services and Department of Health under the Disability Equipment Evaluation Programme (MDA, 2002). An example of a typical evaluation study conducted by DEAC is the recent study of chair raisers. Rising from a chair unassisted is a prerequisite to independent living (Chan et al., 1999), and a combination of movement strategies and furniture modification can facilitate easier sitting to standing. Fitting raisers to chairs is a relatively inexpensive method of furniture modification, and is suitable for elderly and disabled people, and those recovering from surgery such as hip replacement. However, forty different types of chair and bed raisers have been identified making selection of the most appropriate raiser difficult.

The selected criteria for product appraisal were stability, safety, aesthetics and ease of cleaning. Technical tests of stability and safety were applied in the laboratory and raisers were marked as either pass or fail with respect to British Standards Guidelines. In addition to these technical tests, the views of the people

who use the equipment were felt to be an essential aspect of product evaluation. In particular, it has been found that aesthetic appeal is an important consideration affecting user confidence of use (Alexander et al., 1996). Users were therefore invited to visit the laboratory to review a range of chair raisers on one of two types of chairs – either a castor chair or leg chair. They had the opportunity to sit on the chairs with the raisers fitted. Then they were asked to assess their perceptions of the raisers' comfort, convenience, safety and aesthetics. However, the problems with this approach were twofold, firstly it was difficult for elderly and disabled participants to make the journey to the laboratory (based in Derby City General Hospital). Secondly, the manual handling operations involved in manoeuvring the raisers on and off the chairs required two people, had safety risks and were time consuming for evaluators.

It was considered that virtual reality (VR) may provide an alternative review medium and an opportunity for participants to assess a larger number of chair and raiser combinations. Desktop VR has been found to be a useful tool to support co-operative design, where users are involved in product or workplace specification early on in the design process (Davies, 2000; Eastgate, 2001). Obviously there is a trade-off here in that Virtual Environment (VE) participants do not have the opportunity to physically sit on the chairs, and the visual quality of a virtual model will inevitably be less than of a real model. Therefore one of the aims of this project was to assess how differences between the real and virtual environments might affect patient judgement. It was also important to take into account acceptability and usability issues of VR technology, particularly for elderly users although studies have demonstrated that elderly people can successfully use desktop virtual reality (Stanton et al (in press); Rose et al, 1999; Rizzo, 2001; Karlsson et al, 2000).

This paper presents a feasibility study conducted to assess whether virtual reality is an appropriate tool for assessment of rehabilitation equipment, specifically to allow elderly and disabled individuals to evaluate chair raisers for the home. Measures of success included quality of representation of the real product and design of the virtual environment interface (reviewed by Occupational Therapists), usability and acceptability of the VR system particularly for elderly users, and comparison of results in user selection preferences between real and VE evaluation settings.

## 2. VE DESIGN

A Superscape VRT desktop Virtual Environment was developed to allow visualisation of different raisers when placed on different types of chairs. The VE was modelled on the room at Derby City General Hospital that is currently used for patient assessment and rehabilitation, and was used for the laboratory based review of the chair raisers. The requirements of the VE were that it should allow the Occupational Therapist to select chair and raiser combinations to present to the user. The user should then be able to view these from different angles, close up and from a distance, navigating freely around the VE if required. An iterative user-centred design process was employed when designing the VE, involving a number of meetings between VE designers and rehabilitation therapists and ergonomists.

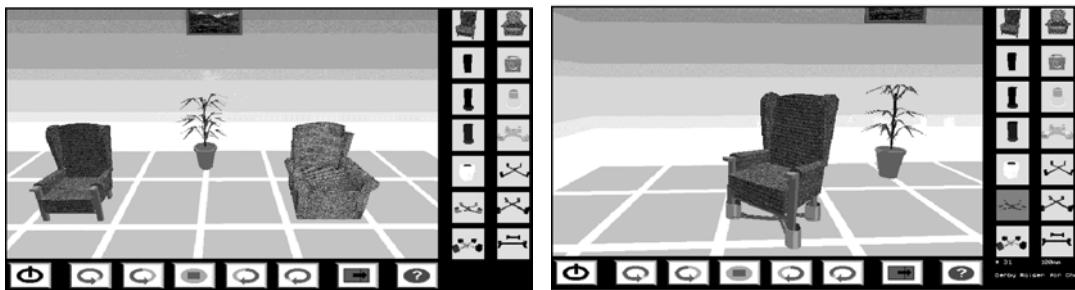
Figure 1 shows screenshots of the VE. The interface comprises a window into the VE room that contains two different types of chair, one with rectangular legs, and one with castors (see figure 1a). The two-dimensional overlay (see Wilson, Eastgate & D'Cruz, 2002) around two edges of the screen contains a number of icons that allow the user to select chair and raiser combinations and view them from different angles. On the right hand side of the screen the user can select a chair and raiser type to examine in close detail (see figure 1b). The icons below the screen are used to change the user viewpoint and rotate the chair. These icons were included to allow users who have little or no experience of VE navigation to easily view the chairs from a number of different angles.

## 3. PRODUCT ASSESSMENT

### 3.1 Product selection

A search of the product literature and the DLF Hamilton Index (2000) identified over 40 different varieties of chair and bed raisers available on the UK market. Of these 24 were sold as chair raisers. These were grouped according their main design features, i.e. whether they were linked or individual. Two armchairs were purchased, one on legs and one on castors. Twelve chair raisers were selected to fit these chairs:

- Six to fit the chair on legs, and six to fit the chair on castors
- Six were individual raisers and six were linked raisers.



**Figure 1.** Screenshots showing an overview of the two chairs (a) and a close up view of chair with linked raisers attached (b).

### 3.2 Technical tests of chair raisers

Technical tests were conducted to assess each of the chair raiser designs on the appropriate style of chair for:

- stability
- safe hoist access
- moving
- measurements
- mass

Mechanical tests of stability and safety were applied in accordance with the stability overturning tests for chairs described in BS EN 1022:1997, and a modified impact test for chairs, adapted from BS EN 4875: Part 1: 1985, Strength and stability of furniture - methods for determination of strength of chairs and stools, Section 7.7.1 Back impact test. The results from these tests were recorded and are presented as either "pass" or "fail".

## 4. USER EVALUATION STUDY

### 4.1 Participants

53 participants were recruited who were either aged over 70 years, had a disability or had used raisers either currently or the past. 36 participants viewed the raisers in the VE, and 17 in the laboratory. Of the participants who took part in the VE trials, 67% had not used a computer before.

### 4.2 Materials

The participants were required to rate the chairs on three aspects after having viewed the raisers in either the laboratory or virtual environment during a semi structured interview.

1. Participants were asked how safe they thought they would feel with sitting on or standing from the chair with the particular chair/raiser combination viewed, from "very safe" to "very unsafe".
2. They were also asked to rate how convenient they felt the raiser/chair combination would be for cleaning, and responded on a scale from "Very convenient" to "Very inconvenient".
3. They were asked to explain their comments and reasons for giving ratings
4. The participants' use of and reaction to the VE was observed.

### 4.3 Procedure

**4.3.1 Laboratory trials using raisers fitted to chairs.** Seventeen participants sat in and stood from the chairs fitted with the raisers. A semi structured interview, video and observation were used to gather a variety of data about safety when sitting and standing, perceived ease of cleaning around chairs with raisers fitted and personal acceptability.

**4.3.2 Trials using the Virtual Environment.** The portable desktop Virtual Environment (VE) was taken into day centres where 36 participants viewed the raisers from all aspects on either a laptop screen or a large screen.

A semi structured interview, video and observation were used to gather a variety of data about perceived safety when sitting and standing, perceived ease of cleaning around chairs with raisers fitted, personal acceptability and ease of use of the VE. Participants were invited to control the VE themselves, but if they did not feel confident to use the input device then the facilitator controlled the VE for them.

## 5. RESULTS

### 5.1 Usability and acceptance of VE by older people

78% of participants in the VR trials found the system easy to use, and this was supported by observational data that illustrated that although some participants were initially reluctant to use the computer, once they did they enjoyed the experience and were pleased they had been able to use the VE themselves.

Generally the mouse was the preferred interaction device, although some participants thought that it was easier to find a better view within the VE using the joystick. The main problems observed when using the controls were: positioning the cursor (overshooting), following the cursor on screen and using the device to select (positioning and clicking simultaneously). Generally the large screen projected display was viewed in preference to the small lap top screen as the image was easier to see, although some participants used the small (laptop) monitor when operating the interaction device.

### 5.2 Comparison of results in user selection preferences between real and VE settings

**5.2.1 Safety when sitting and standing from a chair.** The ratings of perceived safety of the chairs when either sitting in them or standing from them were compared using a Mann Whitney U test. For ratings of safety when sitting, three raisers yielded significantly different ratings – raisers 1, 2 & 7 (raiser 1: U=3; N=5,6; p<0.05; raiser 2: U=2; N=3,6; p<0.05; raiser 7: U=2; N=4,6; p<0.05). In all cases the raiser was rated as more unsafe when viewed on the VE compared with the rating obtained in the laboratory. For standing from the chair, the ratings for only one raiser – raiser 2 – were significantly different for the VE and laboratory (U=2.5; N=3,6; p<0.05).

In the mechanical testing trials raisers 1, 2, 8 & 10 failed to be passed as safe. In the laboratory trials, these were ranked as 3<sup>rd</sup>, =6<sup>th</sup>, 12<sup>th</sup> and =4<sup>th</sup> respectively (where 1<sup>st</sup> is the raiser perceived as being the most safe), and in the VE trials, they were ranked as 12<sup>th</sup>, 11<sup>th</sup>, =5<sup>th</sup> and =8<sup>th</sup>. Therefore there is some indication that the judgements of safety in the VE matched the results of the technical testing more closely than when the raisers were viewed in the laboratory. Table 1 summarises the comparison between these three types of evaluation.

**Table 1.** Comparison of assessments of chair/raiser combination safety from laboratory, VE and technical evaluations.

	Raiser no.											
	1	2	3	4	5	6	7	8	9	10	11	12
<b>Safety ranking from laboratory</b>	3	=6	2	11	=9	=4	1	12	=6	=4	=9	8
<b>Safety ranking from VE</b>	12	11	=8	=1	=1	=5	4	=5	=5	=8	10	3
<b>Pass/fail technical test</b>	X	X	✓	✓	✓	✓	✓	X	✓	X	✓	✓

**5.2.2 Cleaning.** The responses to the rating questions were compared for each raiser viewed either in the laboratory or virtual environment. The significance of the differences between the ratings were also compared. There was no significant difference of the rating of ease of cleaning for any of the raisers between the laboratory and virtual environment. However, overall, the ratings for the two modes of viewing were not correlated (Spearman's  $r = 0.282$ ,  $N=12$ ,  $p>0.05$ ), indicating that there was some difference in the rank order of the raiser/chair combinations in perceived ease of cleaning. In general, the chair raiser combinations were rated as being slightly more inconvenient to clean when viewed in the VE compared to the ratings given when viewed in the laboratory.

## 6. CONCLUSIONS

Almost all of the participants were able to study the VE and form an opinion on the raiser from the image displayed, however many participants did not use the interactive capabilities of the VE in order to make their judgements. Some also requested further information about the raisers in order to formulate their opinions (e.g. what material it was made from, size, colour, etc.).

It was commented that the VE would be a useful tool to help narrow down a choice of raisers to trial in real life. The VE alone would probably not be sufficient to make a final choice.

On examination of the characteristics of the particular raisers for which the ratings differed, an interesting hypothesis can be formed. The raiser for which perceived safety ratings differed for both sitting and standing was raiser 2, a wooden block with indentations that is designed to be placed on the legs of the chair. As this raiser is made from wood, compared to the others that are predominantly plastic or metal, it is more aesthetically pleasing, and is likely to complement the décor of a house and appear less intrusive. The “wooden” appearance of the block would have been more noticeable when viewing the real block compared to viewing the virtual block. Therefore it is possible that the pleasant aesthetic quality of this raiser may have made participants biased towards it, and thus reluctant to rate it as unsafe. This is analogous to general findings in product design and consumer behaviour. However, it does suggest the possibility of artificially altering details of objects to be assessed in a VE in order to deliberately bias judgements from users.

## 7. IMPLICATIONS FOR FUTURE DEVELOPMENT

The study presented in this paper does provide an illustration that VR may be a useful tool in the context of rehabilitation equipment assessment. The VE allows users to switch between raiser types quickly, so different types of raisers can be easily compared. The VE is also displayed via a laptop and small projector, so is portable, avoiding the need for participants to travel to the hospital. This should enable rehabilitation therapists to access a wider population sample. Potential extensions to the relatively simple VE used in this project could be to allow images of participants' own homes or furniture to be rapidly included, to make the equipment appear in more familiar surroundings. The observational and subjective response indicated that the population used in this study, despite their relatively low level of familiarity with the technology, were happy to use the VR equipment, although some felt that they would have liked their conclusions to be reinforced by viewing the real objects.

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