University of Reading

Proceedings of the 8th international conference on disability, virtual reality and associated technologies (ICDVRAT 2010)

Book

Published Version

Conference Proceedings

Sharkey, P. and Sanchez, J., eds. (2010) Proceedings of the 8th international conference on disability, virtual reality and associated technologies (ICDVRAT 2010). ICDVRAT. The University of Reading, Reading, UK, pp305. ISBN 9780704915022 Available at https://centaur.reading.ac.uk/27451/

It is advisable to refer to the publisher's version if you intend to cite from the work. See Guidance on citing.

Publisher: The University of Reading

All outputs in CentAUR are protected by Intellectual Property Rights law, including copyright law. Copyright and IPR is retained by the creators or other copyright holders. Terms and conditions for use of this material are defined in the End User Agreement.

www.reading.ac.uk/centaur

University of Reading

CentAUR

Central Archive at the University of Reading

Reading's research outputs online

The 8th International Conference on

Disability, Virtual Reality and Associated Technologies

Proceedings

Edited by:

Paul Sharkey
Jaime Sánchez

31 August to 2 September, 2010

Viña del Mar / Valparaíso, Chile

AN INTERNATIONAL SOCIETY FOR VIRTUAL REHABILITATION CONFERENCE

ICDVRAT 2010

The papers appearing in this book comprise the proceedings of the 8th International Conference on Disability, Virtual Reality and Associated Technologies, held between the 30th August and 2nd of September, 2010 in the Viña del Mar/Valparaíso, Chile. The papers presented reflect the authors' opinions and are published as presented and without change (formatting and minor editing excepted). Their inclusion in this publication does not necessarily constitute endorsement by the editors, ICDVRAT, or the University of Reading.

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

> A. B. Author(s), "Title of paper", *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P. M. Sharkey, J. Sánchez (Eds), page numbers, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Proceedings reference number: ISBN 978 07049 15022

Published by

The University of Reading

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

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

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

Copyright ©2010 ICDVRAT and the University of Reading.

Copying of material in these Proceedings for internal or personal use, or for the internal or personal use of specific clients is permitted without charge by ICDVRAT and the University of Reading. Other copying for republication, resale, advertising, or promotion, or any form of systematic or multiple reproduction of any material from these Proceedings is prohibited except with permission in writing from ICDVRAT.

Printed in the UK.

Conference Schedule at a Glance

Tuesday, 30 August, 2010

08:30	Registration opens from 08:30
09:10	Welcome
09:20 – 11:00	Session I: Navigation & Motion
11:00	Coffee
11:30 – 12:45	Session II: Visual Impairment
12:45	Lunch
14:20 – 16:00	Session III: Brain Injury & Memory Training
16:00	Coffee
16:30 – 17:45	Session IV: Virtual Environments: Design & Analysis
19:00	Reception

Wednesday, 1 September, 2010

09:00 – 11:00	Session V: Upper Limb & Hand Rehabilitation
11:00	Coffee
11:30 – 12:45	Session VI: ArtAbilitation
12:45	Lunch
14:20 – 16:00	Session VII: Games for Rehabilitation
16:00	Coffee
16:30 – 17:45	Session VIII: Poster & Breakout Session
19:00	Banquet

Thursday, 2 September, 2010

09:00 – 11:00	Session IX: Balance & Gait
11:00	Coffee
11:30 – 13:10	Session X: Speech & Audio
13:10	Lunch
14:00	Conference Closed

©2010 ICDVRAT; ISBN 978 07049 15022

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

Contents

Abstracts & Information on Viña del Mar/Valparaíso

xv *Viña del Mar, Valparaíso*, **J Sánchez**, University of Chile, CHILE

xvii *Abstracts from all papers*

1 – 290 *Full Papers*

291 – 302 *Short Papers*

303 – 304 *Author index*

Session I Navigation & Motion
Session Chair: Jaime Sánchez

1 *Exploring the intelligent agents for controlling user navigation in 3D games for cognitive stimulation*, **R M E M Costa**, **D S Souza**, **I Mendonça**, Universidade do Estado do Rio de Janeiro, BRAZIL

7 *Assessing navigation in real and virtual environments: a validation study*, **S T Koenig**, **G P Crucian**, **J C Dalrymple-Alford**, **A Dünser**, University of Canterbury, NEW ZEALAND

17 *Wearable device to assist independent living*, **R J McCrindle**, **V M Williams**, **C R Victor**, **A P Harvey**, **S R Nyman**, **J Barrett**, **H Hogarth**, **P Levene**, **R Smith**, **P Panek**, **G Edelmayer**, **P Mayer**, **P Needham**, **N Floratos**, University of Reading/Brunel University/ Bournemouth University/Docobo Limited, UK, Technical University of Vienna, AUSTRIA and e-ISOTIS, GREECE

27 *Designing a workplace for workers with motion disability with a computer simulation and virtual reality techniques*, **P Budziszewski**, **A Grabowski**, **T Tokarski**, **M Dzwiarek**, **B Kurkus-Rozowska**, **J Jankowski**, Central Institute for Labour Protection – National Research Institute, POLAND

Session II Visual Impairment
Session Chair: Mauricio Sáenz

33 *Listening to complexity: blind people's learning about gas particles through a sonified model*, **O Lahav**, **S T Levy**, Tel-Aviv University/University of Haifa, ISRAEL

41 *Using augmented reality to support the understanding of three-dimensional concepts by blind people*, **C Kirner**, **T G Kirner**, **R S Wataya**, **J A Valente**, Federal University of Itajuba/Adventist University of Sao Paulo/State University of Campinas, BRAZIL

51 *Visual tracking and audio-based interfaces for the navigation of people who are blind*, **J Sánchez**, **A Tadres**, University of Chile, CHILE

©2010 ICDVRAT; ISBN 978 07049 15022

Session III Brain Injury & Memory Training
Session Chair: Pawel Budziszewski

61 *PiTaSu: a wearable interface for assisting senior citizens with memory problems*, **T Kuroda**, **G Yamamoto**, **D Yoshitake**, **S Hickey**, **J Hyry**, **K Chihara**, **P Pulli**, Kyoto University Hospital/Okayama University/Nara Institute of Science and Technology, JAPAN and University of Oulu, FINLAND

71 *Designing an ecological virtual task in the context of executive functions: preliminary study*, **X Cao**, **A-S Douguet**, **P Fuchs**, **E Klinger**, Arts et Métiers Paristech/Kerpape Rehabilitation Center/MINES ParisTech, FRANCE

79 *Traumatic brain injury memory training: a virtual reality online solution*, **P Gamito**, **J Oliveira**, **J Pacheco**, **D Morais**, **T Saraiva**, **R Lacerda**, **A Baptista**, **N Santos**, **F Soares**, **L Gamito**, **P Rosa**, Universidade Lusófona de Humanidades e Tecnologias/Centro de Medicina de Reabilitação de Alcoitão/Clínica São João de Deus/Centro de Investigação Social/Instituto Universitário de Lisboa, PORTUGAL

85 *Impact of the physical field of view on the performance in a purchasing task in the VAP-S for patients with brain injury*, **H Cherni**, **A Kadri**, **A Tarruella**, **P-A Joseph**, **E Klinger**, Arts Métiers Paristech/Université Victor Segalen de Bordeaux, FRANCE

Session IV Virtual Environments: Design & Analysis
Session Chair: Sebastian Koenig

93 *Participatory design with children with autism: the development of collaborative virtual environments*, **L Millen**, **S V Cobb**, **H Patel**, University of Nottingham, UK

103 *Post traumatic stress disorder treatment with virtual reality exposure for criminal violence: a case study in assault with violence*, **A De la Rosa-Gómez**, **G Cárdenas-López**, Universidad Nacional Autónoma de México, MÉXICO

109 PAPER WITHDRAWN: PAGES 109 – 114 REMOVED

©2010 ICDVRAT; ISBN 978 07049 15022

Session V Upper Limb & Hand Rehabilitation
Session Chair: Sarah Kruger

115 *Stroke rehabilitation using m-Health Care and 3D virtual environments – work in progress*, **J Broeren**, **L Pareto**, **B Johansson**, **C Ljungberg**, **M Rydmark**, Trollhättan/Uddevalla NU-Hospital Organization, SWEDEN

123 *Simple camera tracking virtual reality system for evaluation of wrist range of motion*, **D Shefer Eini**, **N Ratzon**, **A A Rizzo**, **S-C Yeh**, **B S Lange**, **B Yafa**, **A Dietz**, **P L Weiss**, **R Kizony**, Tel-Aviv University/Chaim Sheba Medical Center at Tel Hashomer/University of Haifa/Ono Academic College, ISRAEL and University of Southern California, USA

131 *Integrated arm and hand training using adaptive robotics and virtual reality simulations*, **A S Merians**, **G G Fluet**, **Q Qiu**, **S Saleh**, **I Lafond**, **S V Adamovich**, University of Medicine and Dentistry of New Jersey, USA

139 *Study to evaluate a low cost virtual reality system for home based rehabilitation of the upper limb following stroke*, **P J Standen**, **D J Brown**, **S Battersby**, **M Walker**, **L Connell**, **A Richardson**, University of Nottingham/ Nottingham Trent University/Erewash Community Occupational Therapy Service, UK

147 *Remote monitoring and quantification of upper limb and hand function in chronic disability conditions*, **S H Brown**, **J Langan**, **K L Kern**, **E A Hurvitz**, University of Michigan, USA

Session VI ArtAbilitation
Session Chair: Paul Sharkey

157 *Light Arrays: a system for extended engagement*, **D Wilde**, **A Cassinelli**, **A Zerroug**, **R J N Helmer**, **M Ishikawa**, Tokyo University, JAPAN and Monash University/ Commonwealth Scientific and Industrial Research Organisation, AUSTRALIA

165 *Warrior's Journey – a path to healing through narrative exploration*, **J F Morie**, **K Haynes**, **E Chance**, University of Southern California, USA

175 *Extending body & imagination: moving to move*, **D Wilde**, **R J N Helmer**, **M Miles**, Tokyo University, JAPAN and Monash University/ Commonwealth Scientific and Industrial Research Organisation, AUSTRALIA

©2010 ICDVRAT; ISBN 978 07049 15022

Session VII Games for Rehabilitation
Session Chair: Susan Brown

185 *Games for rehabilitation: the voice of the players*, **S M Flynn**, **B S Lange**, Blue Marble Game Co./University of Southern California, USA

195 *Designing engaging, playable games for rehabilitation*, **J W Burke**, **M D J McNeill**, **D K Charles**, **P J Morrow**, **J H Crosbie**, **S M McDonough**, University of Ulster, UK

203 *Designing studies for requirements and modelling of users for an accessible set-top box*, **P Langdon**, **M F Gonzalez**, **P Biswas**, University of Cambridge, UK

213 *SimCoach: an intelligent virtual human system for providing healthcare information and support*, **A A Rizzo**, **B S Lange**, **J G Buckwalter**, **E Forbell**, **J Kim**, **K Sagae**, **J Williams**, **J Difede**, **B O Rothbaum**, **G Reger**, **T Parsons**, **P Kenny**, University of Southern California/Cornell University/Emory University, USA

Session VIII Balance & Gait
Session Chair: Sheryl Flynn

223 *Development of an interactive stepping game to reduce falls in the elderly*, **B S Lange**, **S M Flynn**, **C Y Chang**, **W Liang**, **C L Chieng**, **Y Si**, **C Nanavati**, **A A Rizzo**, University of Southern California, USA

229 *Virtual reality approach to gait training in service members with lower extremity amputations*, **S E Kruger**, Walter Reed Army Medical Center, USA

235 *Continuation of balance training for stroke subjects in home environment using virtual reality*, **I Cikajlo**, **M Rudolf**, **N Goljar**, **Z Matjacic**, University Rehabilitation Institute, SLOVENIA

241 *Audio-visual biofeedback system for postural control*, **M Milosevic**, **K M V McConville**, Ryerson University, CANADA

249 *Development of an interactive rehabilitation game using the Nintendo® WiiFit™ Balance Board for people with neurological injury*, **B S Lange**, **S M Flynn**, **C Y Chang**, **A Ahmed**, **Y Geng**, **K Utsav**, **M Xu**, **D Seok**, **S Cheng**, **A A Rizzo**, University of Southern California, USA

©2010 ICDVRAT; ISBN 978 07049 15022

Session IX Speech & Audio
Session Chair: Orly Lahav

255 *Development of a voice-based rhythm game for training speech motor skills of children with speech motor disorders*, **D Umanski**, **D Kogovšek**, **M Ozbič**, **N O Schiller**, Leiden University, THE NETHERLANDS and University of Ljubljana, SLOVENIA

263 *Robotic vocalization training system for the auditory-impaired*, **M Kitani**, **T Hara**, **H Hanada**, **H Sawada**, Kagawa University, JAPAN

273 *Automatic speech recognition for assistive technology devices*, **A P Harvey**, **R J McCrindle**, **K Lundqvist**, **P Parslow**, University of Reading, UK

283 *Basic study toward automatic generation of glove-type command input device with optimal number of sensors*, **Y Tabata**, **T Kuroda**, **K Okamoto**, Kyoto College of Medical Science/Kyoto University Hospital, JAPAN

Posters Poster Session

291 *Virtual environments for exposure in obsessive-compulsive disorder*, **G Cárdenas-López**, **S Muñoz**, Universidad Nacional Autónoma de México, MÉXICO

295 *Integrative approach for designing collaborative technologies for social competence training in children with autism spectrum conditions*, **S V Cobb**, **L Millen**, **T Glover**, **S Parsons**, **S Garib-Penna**, **P L Weiss**, **E Gal**, **N Bauminger**, **S Eden**, **M Zancanaro**, **L Giusti**, University of Nottingham/University of Birmingham, UK and University of Haifa, Bar Ilan University, ISRAEL

299 *Videogame for improving orientation and mobility in blind children*, **J Sánchez**, **J P Rodríguez**, Universidad de Chile, CHILE

303 Author Index

Internet address references within the papers presented in this volume were accessed and checked to be valid during the week 1–8 July 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Conference Sponsors

The main sponsors of ICDVRAT 2010 are the University of Reading, UK and the University of Chile, Chile.

The conference is grateful for further support from Aalborg University Esbjerg/Esbjerg Technical Institute, Denmark and SoundScapes. Additional help in publicising the conference has been gratefully received from vrpsych-l@usc.edu, amongst many others.

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

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 2010 Graphic). Eric Phipps and David Angus (both of Project DISCOVER) and *sckelp* may be contacted through ICDVRAT.

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

Conference Organisation

Conference General Chair

Jaime Sánchez, Universidad de Chile, Chile

ICDVRAT Programme Chair

Paul Sharkey, University of Reading, UK

ArtAbilitation Programme Chair

Tony Brooks, Aalborg Universitet Esbjerg, Denmark

International Programme Committee

Robert Astur, Yale University, USA
Willem-Paul Brinkman, Delft University of Technology, Netherlands
Jurgen Broeren, Göteborg University, Sweden
Jane Broida, Metropolitan State College of Denver, USA
Tony Brooks, Aalborg Universitet Esbjerg, Denmark
David Brown, Nottingham Trent University, UK
Ben Challis, University of Glamorgan, UK
Sue Cobb, University of Nottingham, UK
Jean Detheux, Artist, Montréal, Canada
Judith Deutsch, University of Medicine & Dentistry of New Jersey, USA
Sheryl Flynn, Blue Marble Game Co., USA
Joyce Fung, McGill University, Canada
Pedro Gamito, Universidade Lusófona de Humanidades e Tecnologias, Portugal
Rolf Gehlhaar, University of Coventry, UK
Luis Girao, Coventry University, UK
Colin Harrison, University of Strathclyde, UK
William Harwin, University of Reading, UK
Bruno Herbelin, L'Ecole Polytechnique Fédérale de Lausanne, Switzerland
Maureen Holden, Northeastern University, Boston, USA
Faustina Hwang, University of Reading, UK
Wendy Kaey-Bright, Cardiff School of Art and Design, Wales
Emily Keshner, Temple University Philadelphia, USA
Rachel Kizony, University of Haifa, Israel
Evelyne Klinger, Arts et Metier ParisTech, France
Tomohiro Kuroda, Osaka University, Japan
Pat Langdon, University of Cambridge, UK
Belinda Lange, University of Southern California, Los Angeles, USA
Mindy Levin, McGill University, Canada
Craig Lindley, Blekinge Technical Institute, Sweden
Pedro Lopes-dos-Santos, University of Porto, Portugal
Rachel McCrindle, University of Reading, UK
Suzanne McDonough, University of Ulster, UK
Alma Merians, University of Medicine & Dentistry of New Jersey, USA
Alessio Murgia, University of Reading, UK

Alice O'Grady, University of Leeds, UK
Mark Palmer, University of the West of England, UK
Lena Pareto, University of Trollhättan-Uddevalla, Sweden
Eva Petersson, Aalborg Universitet Esbjerg, Denmark
John Rae, Roehampton University, UK
Albert (Skip) Rizzo, University of Southern California, Los Angeles, USA
Martin Rydmark, Göteborg University, Sweden
Jaime Sánchez, Universidad de Chile, Chile
Hideyuki Sawada, Kagawa University, Japan
Cecília Sik Lányi, University of Veszprém, Hungary
Paul Sharkey, University of Reading, UK
Andrew Cyrus Smith, African Advanced Institute for Information & Communication Technology, South Africa
Adam Sporka, Czech Tecnical University Prague, Czech Republic
P J Standen, University of Nottingham, UK
Daniel Thalmann, L'Ecole Polytechnique Fédérale de Lausanne, Switzerland
Raewyn Turner, Interdisciplinary Artist, New Zealand
Charles van der Mast, Delft University of Technology, Netherlands
Mattias Wallergård, Lunds Universitet, Sweden
Patrice L (Tamar) Weiss, University of Haifa, Israel
Ceri Williams, Musician/Educator, Newport, Wales, UK
Paul Wilson, University of Hull, UK

Conference Organising Committee

Jaime Sánchez, Universidad de Chile, Chile (Chair)
Mauricio Sáenz Correa, University of Chile, Chile
Susana Benavides Castro, University of Chile, Chile
Carlos Reyes López, University of Chile, Chile
Lucía Vargas González, University of Chile, Chile
Paul Sharkey, University of Reading, UK

ICDVRAT Conference Steering Committee

Paul Sharkey, University of Reading, UK (Chair)
Tony Brooks, Aalborg Universitet Esbjerg, Denmark
David Brown, Nottingham Trent University, UK
Sue Cobb, University of Nottingham, UK
Evelyne Klinger, Arts et Metier ParisTech, France
Pedro Lopes-dos-Santos, University of Porto, Portugal
Rachel McCrindle, University of Reading, UK
Albert (Skip) Rizzo, University of Southern California, Los Angeles, USA
Jaime Sánchez, Universidad de Chile, Chile
Cecília Sik Lányi, University of Veszprém, Hungary
P J Standen, University of Nottingham, UK
Patrice L (Tamar) Weiss, University of Haifa, Israel

Conference Series Archive

Paul Sharkey, University of Reading, UK

©2010 ICDVRAT; ISBN 978 07049 15022

Introduction

The purpose of the 8th International Conference on Disability, Virtual Reality and Associated Technologies (ICDVRAT 2010) 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.

After a peer review process, the International Programme Committee selected 35 full papers for presentation at the conference, collected into 9 plenary sessions: ArtAbilitation; Balance & Gait; Brain Injury & Memory Training; Games for Rehabilitation; Navigation & Motion; Speech & Audio; Upper Limb & Hand Rehabilitation; Virtual Environments: Design & Analysis; Visual Impairment. There will be an additional Poster Session with 3 poster presentations. The conference will be held over three days between the 31st August and 2nd September at the Hotel San Martín, Viña del Mar, Chile.

ICDVRAT is now in its 14th year, with biennial conferences in the series previously held in Maidenhead, UK (1996), Skövde, Sweden (1998), Alghero, Sardinia, Italy (2000), Veszprém, Hungary (2002), Oxford, UK (2004), Esbjerg, Denmark (2006) and Maia & Porto, Portugal.

In 2006 and 2008, ICDVRAT was held in conjunction with ArtAbilitation, in 2006 as a parallel conference and in 2008 as an integrated plenary conference, the latter having three sessions spanning ArtAbilitation, Helping through Music and Interpretations. It was envisaged that ArtAbilitation could remain integrated with ICDVRAT in 2010. However, there were insufficient submissions to enable this, though ArtAbilitation remains as one of the sessions in this conference. In future years, ArtAbilitation and ICDVRAT will return to being separate conferences, though papers in this area will still remain welcome at future ICDVRAT events.

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

Acknowledgements

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

We would like to take this opportunity to thanks Tony Brooks for his invaluable support for hosting both conferences in Esbjerg, and his contributions to the subsequent two meetings.

On behalf of ICDVRAT 2010, we welcome all delegates to the Conference and sincerely hope that delegates find the conference to be of great interest.

Jaime Sánchez and Paul Sharkey

Tháinig Long ó Valparaíso

Pádraig de Brún, 1889-1960

Tháinig long ó Valparaíso
Scaoileadh téad a seol sa chuan
Chuir a hainm dom i gcuimhne
Ríocht na Gréine, Tír na mBua.

"Gluais," ar sí, "ar thuras fada
Liom ó scamall is ó cheo
Tá fé shleasaibh gorm Andes
Cathair scáfar, glé mar sheod."

Bhíos óg is ní imeoinnse
Am an dóchais, tus mo shaoil
Chreideas fós go raibh i ndán dom
Iontaisí na ndán 's na scéal.

Ghluais an long thar lintibh mara
Fad ó shin is a crann mar ór
Scríobh a scéal ar phár na hoíche
Ard i rian na réaltean mór.

Fillfidh sí aris chugam áfach
Chífead cathair bhán fén sléibh
Le hais mara na síochána
Creidim fós beagnach, a Dhé.

Original in Gaelic,
the old tongue of Ireland

There came a ship from Valparaíso
Slackened sail ropes in the bay
Her name evoked an image of
A sunlit kingdom, a land of wonders.

"Come ," she said, "away with me"
"Away from cloud and from the mist
There you'll find, beneath the blue Andes,
An awesome city, shining like a gem."

But I was young and would not travel
My time of hope, my life beginning;
My destiny lay, I still believed,
In poems and stories yet to unfold.

The ship sailed over the sea's horizon
Far from me, its mast like gold
She wrote her story on the parchment
High amidst the great stars that night.

She will return to me, however
The white mountain city, I'll still perceive
Beside that ocean of peace
I shall yet be, if I believe.

English translation:
John Brendan Sharkey

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

Viña del Mar / Valparaíso, Chile

Jaime Sánchez

Universidad de Chile, CHILE

Founded as a seaside resort for the upper class, Viña del Mar emerged from the division of the "La Viña del Mar" hacienda of Dolores Perez. Her daughter and sole heiress, Mercedes Alvarez, married the businessman and politician José Francisco Vergara, who created a plan that would give birth to this coastal city. Shortly after the plan was passed in 1874, the Municipality of Viña del Mar was created.

Currently, Viña del Mar is recognized as the Tourism Capital of Chile, and as a "Garden City" due to the fact that it is surrounded by large swaths of green areas. The city has 13 beaches (approximately 3.5 kilometers), the most important of which is located in Reñaca, the city's main beach, which has a life of its own and includes all the installations and infrastructure necessary to receive a large number of tourists. It has a very unique architecture, with beautiful residential neighborhoods complete with chalets surrounded by beautiful gardens and a number of modern high-rises, most of which are located on the beachfront. In walking through its streets, and as a testimony to the golden age of Viña del Mar, one can find palaces and antique buildings that date back to the beginning of the 20th century.

Neighboring the Garden City is Valparaíso, one of the oldest cities in Chile. Its origins date back to 1536, and in its position as the main port of the kingdom, it played a determining role in the process of national emancipation. It is the headquarters of the nation's Legislative Branch, and the declared capital of the country's cultural institutionality, housing the regional government as well as the base of the Chilean Navy.

The urban configuration of Valparaíso is determined by its local topography, which is dominated by 44 hills that form a natural amphitheatre with a view of the ocean that merges with the sky. The streets at the foot of the hills, the thin alleyways, the stairs, lookouts, the houses hanging out over the abyss and that seem to be within arms' reach of the passengers riding the age-old elevators, the rocky sea-swept crevices, are all traits of a city that admires itself from the hill tops.

Getting to Know the City

In beginning a walk down San Martin Boulevard, one can find the Viña del Mar Casino, which was inaugurated on December 31st of 1930. Today the Municipal Casino is a symbol of the garden city, and is considered to be one of the most complete and modern casinos in the world, with cabaret shows in which several top artists have performed. The main aesthetic attraction, in addition to its refined architecture, is that it possesses a privileged ocean-side view. In continuing down San Martín Avenue, one can find the most famous restaurants and pubs in the city. During the day, an excellent panorama is to dine in one of the many fine restaurants in the area, accompanied by a delicious Chilean wine. When the night falls, San Martín Avenue becomes a bustling center of activity and bohemia.

Another important area of the city is Valparaíso Street, known as "The Heart of Viña". This is an open air shopping market, with restaurants, hotels and traditional spots of the Garden City. It is the main street, and a common meeting point at which the art, culture and commerce of this young city are combined. It is also the civic and financial neighborhood of Viña del Mar. At any of the commercial galleries on Valparaíso Street, one can find bookshops, clothing and sports stores, and fine jewelry. On Valparaíso Street it is normal to see street performances by musicians and artists, cartoonists and portrait artists, which makes for a rather nice family walk.

©2010 ICDVRAT; ISBN 978 07049 15022

At the end of Valparaíso Street is the Plaza Vergara, where the famous Victorian Carriages can be found. For more than 120 years, the people of Viña del Mar and tourists have taken rides in these carriages, and this has become a traditional ride through the city. These elegant horse-drawn carriages date back to the years in which Viña was founded. In addition to the Plaza Vergara, there are three points in the city at which one can walk through the traditional areas of Viña del Mar, and feel as if in Victorian England.

In order to get to know the coastal area of the city, it is an excellent idea to walk down San Martin Avenue towards Las Salinas, to sit on any of the beautiful beaches in this area, sun tanning or enjoying the sunset and the waves. In the year 2000 the open air Naval Canon Museum was inaugurated, where some of the retired pieces of Chilean Navy artillery are exhibited. Some of these canons were used on ships that fought in the War of the Pacific and the Second World War.

History through Buildings

The Quinta Vergara is one of the most beautiful parks in the region. In this park one can find the Vergara Palace, which was built by Madame Blanca Vergara de Errázuriz. Work on the palace, which is predominantly Venetian in style, began in 1906 and it was finished in 1910 under the watchful eye of the architect Ettore Petri. Today the Palace is the home of the Museum of Fine Arts. Also within the confines of the palace there is an amphitheatre, which has been renovated and which receives thousands of visitors every February for the International Music Festival of Viña del Mar, the most prestigious music award ceremony in Latin America.

The Wulff Castle, originally owned by Gustavo Wulff, a German merchant who arrived to Chile in 1881, was built in 1906 in the German-French style, and is based in stone. Afterwards in 1920, a large tower was added as well as an English-style wing. Upon the death of Mr. Wulff in 1946, the castle was passed on to Esperanza Artaza Matta. She had the Castle remodeled into its current form.

In 1906 Mr. Fernando Rioja, a wealthy Spanish banker from Valparaíso, purchased 40,000 square meters within Viña del Mar and had the architect Alredo Azancot build his residence. Known today as the Rioja Palace, it is noted for its salon-like grandeur, the large dining room and the Imperial Hall. As such, the musical lodge with its two interior balconies, the Boulles salon, the pink room, the blue room and the library are all exceptional aspects of this building. This exuberant display is representative of the era of the "Belle Époque" that the wealthy class of Viña del Mar experienced at around 1910. Mr. Fernando Rioja passed away in 1922. His family inhabited the mansion until the death of Madame Sara Ruiz, Rioja's widow, in 1950. In consideration of the palace's cultural and aesthetic value, it is currently a museum in which finely finished furnishings in the Baroque, Imperial, Rococo and Chesterfield styles, brought over from Spain and France, are exhibited within its lavish halls.

The Municipal Theatre, inaugurated on October 11th of 1930, makes up part of the cultural and artistic history of the garden city. Its beautiful and imposing structure is in the classical style, consistent with Corinthian Greco-Roman simplicity, but with an elegance that begins at the entryway, which includes staircases that highlight the facade. Numerous celebrities have performed on its stage, as well as a large number of ballet companies, operas and wide-ranging performances in the world of the performing arts.

©2010 ICDVRAT; ISBN 978 07049 15022

Session I:
Navigation & Motion

Exploring intelligent agents for controlling user navigation in 3D games for cognitive stimulation

R M E M Costa, D S Souza, I Mendonça

Departamento de Informática e Ciência da Computação
Universidade do Estado do Rio de Janeiro – UERJ
Rua S. Francisco Xavier 524 – 6º B
20550-013 – Rio de Janeiro, BRAZIL

ABSTRACT

Despite the many research efforts addressing the development of environments for Virtual Rehabilitation processes, only few of them consider a modeling step before system implementation. Our previous experience in developing virtual environments for stimulating cognitive functions stresses the necessity of adopting some Software Engineering practices. These open new possibilities to extend or integrate the system with others applications. The objective of this paper is to introduce some technical aspects related to modeling and implementing a multi-agent game for training memory and attention. We explore the integration of multi-agent model methodologies and present initial results of an experiment made with two specific languages for building three-dimensional virtual environments.

(a) *(b)*

Figure 1. *Image of the facade of the house (a) and the entrance of the kitchen and the agent (b).*

R M E M Costa, D S Souza, I Mendonça, Exploring the intelligent agents for controlling user navigation in 3D games for cognitive stimulation, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 1−6, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Session I:
Navigation & Motion

Assessing navigation in real and virtual environments: a validation study

S T Koenig[1], G P Crucian[2], J C Dalrymple-Alford[3], A Dünser[4]

[1,4]HIT Lab NZ, University of Canterbury,
Private Bag 4800, Christchurch 8020, NEW ZEALAND

[1,2,3]Department of Psychology, University of Canterbury,
Private Bag 4800, Christchurch 8020, NEW ZEALAND

ABSTRACT

For navigation ability, a transfer of knowledge from virtual training environments to real-world scenarios has been shown in several studies in the past. The purpose of this investigation is to demonstrate the equivalence of a series of navigation tasks in complex real-world and virtual buildings. Instead of testing knowledge transfer in very simple environments, identical tasks are performed in either version of a complex building. 29 participants are shown twelve landmarks, followed by a battery of tasks which are carried out in the real building by half of the participants, whereas the other half performs identical tasks in a virtual model of the same environment. No significant differences or effects were found, but due to the multifaceted nature of the gathered data and large variability within groups, overlap of both groups' distributions was minimal. To discover the underlying factors of this variability, further research is needed. Usability and future development of virtual environments are discussed.

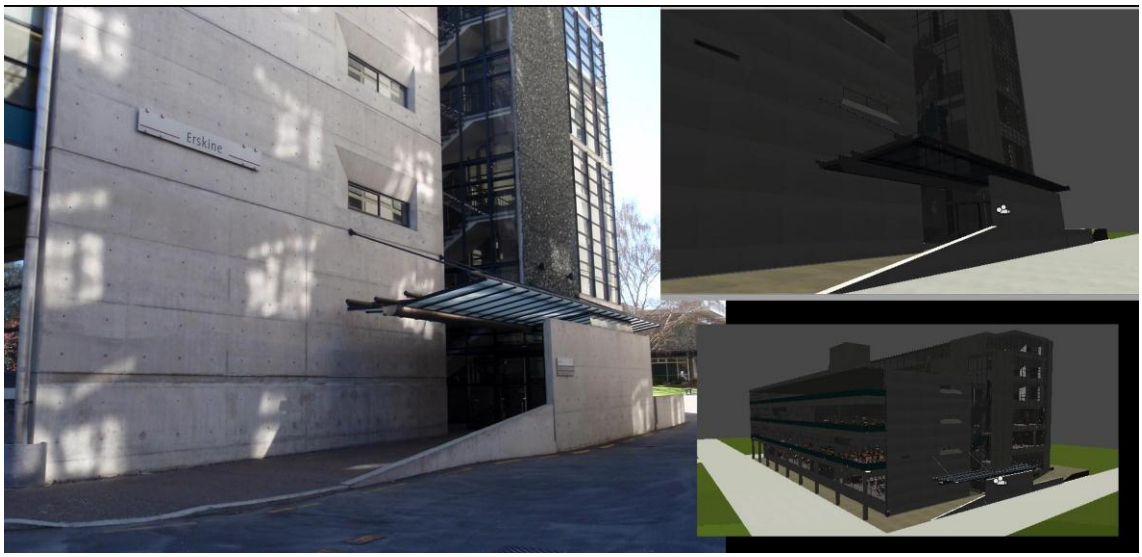


Figure 2. *Erskine Building (side entrance), real building and virtual counterpart rendered in Unity Game*

S T Koenig, G P Crucian, J C Dalrymple-Alford, A Dünser, Assessing navigation in real and virtual environments: a validation study, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 7–16, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Session I:
Navigation & Motion

Wearable device to assist independent living

R J McCrindle[1], V M Williams[2], C R Victor[3], A P Harvey[4], S R Nyman[5], J Barrett[6], H Hogarth[7], P Levene[8], R Smith[9], P Panek[10], G Edelmayer[11], P Mayer[12], P Needham[13], N Floratos[14]

[1,4,6,7]School of Systems Engineering, University of Reading, Whiteknights, Reading, Berkshire, UK

[2,3]School of Health Sciences and Social Care, Brunel University, Kingston Lane, Uxbridge, Middlesex, UK

[5]School of Design, Engineering and Computing, Bournemouth University, Dorset, UK
[8,9]Docobo Limited, 21 High Street, Bookham, Surrey, UK

[10,11,12]Fortec, Technical University of Vienna, A-1040 Favoritenstrasse, Vienna, AUSTRIA

[13]Cardionetics Limited, Grenville Place, Bracknell, Berkshire, UK

[14]e-ISOTIS, 40 Klitaimnistras, Athens, GREECE

ABSTRACT

Older people increasingly want to remain living independently in their own homes. The aim of the ENABLE project is to develop a wearable device that can be used both within and outside of the home to support older people in their daily lives and which can monitor their health status, detect potential problems, provide activity reminders and offer communication and alarm services. In order to determine the specifications and functionality required for development of the device user surveys and focus groups were undertaken and use case analysis and scenario modeling carried out. The project has resulted in the development of a wrist worn device and mobile phone combination that can support and assist older and vulnerable wearers with a range of activities and services both inside and outside of their homes. The device is currently undergoing pilot trials in five European countries. The aim of this paper is to describe the ENABLE device, its features and services, and the infrastructure within which it operates.

Figure 1. *PPT1 Concept A*

Figure 2. *PPT1 Concept B*

Figure 3. *PPT1 Concept C*

R J McCrindle, V M Williams, C R Victor, A P Harvey, S R Nyman, J Barrett, H Hogarth, P Levene, R Smith, P Panek, G Edelmayer, P Mayer, P Needham, N Floratos, Wearable device to assist independent living, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 17–26, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Designing a workplace for workers with motion disability with computer simulation and virtual reality techniques

P Budziszewski, A Grabowski, T Tokarski, M Dźwiarek,
B Kurkus-Rozowska, J Jankowski

Central Institute for Labour Protection – National Research Institute
Czerniakowska 16, Warsaw, POLAND

ABSTRACT

This paper describes preliminary results of a project aimed at adapting workplaces for workers with motion disability with computer simulation and virtual reality techniques. For this task, special software called the Troll and a computer human model with a visualization of maximal arm reach and preferred working space were developed. The Troll can be used to create a virtual working space, to adjust the human model's measurements and constraints to reflect a disabled person, and to analyze necessary modifications. The Troll also makes it possible to conduct research in an immersive virtual reality environment to assess a modified workplace and, if necessary, add further modifications.

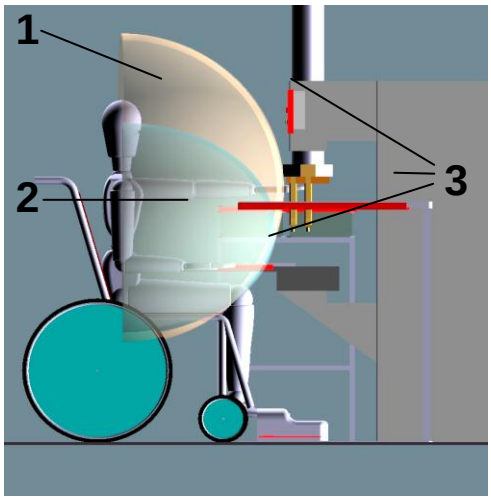


Figure 1. *Computer model of a person in a wheelchair with a visualization of maximal arm reach (1), preferred working space (2) and accessible working areas of the workplace (3)*

P Budziszewski, A Grabowski, T Tokarski, M Dzwiarek, B Kurkus-Rozowska, J Jankowski, Designing a workplace for workers with motion disability with a computer simulation and virtual reality techniques, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 27−32, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Session II:
Visual Impairment

Listening to complexity: blind people's learning about gas particles through a sonified model

O Lahav[1], S T Levy[2]

[1]School of Education, Tel-Aviv University,
Ramat-Aviv, Tel-Aviv, ISRAEL

[2]Faculty of Education, University of Haifa,
Mount Carmel, Haifa, ISRAEL

ABSTRACT

Students who are blind have been integrated at public schools with sighted students. Because most of Science Education curriculum resources are based on visual representations such as diagrams, charts, models (real and digital), and exploration in science laboratories, students who are blind are lack in participating and collecting the information from first hand. The current research project is based on the assumption that the supply of appropriate information through compensatory sensory channels may contribute to science education performance. In the research system - Listen to complexity system the user is interacting with dynamic objects in a real life scenario.

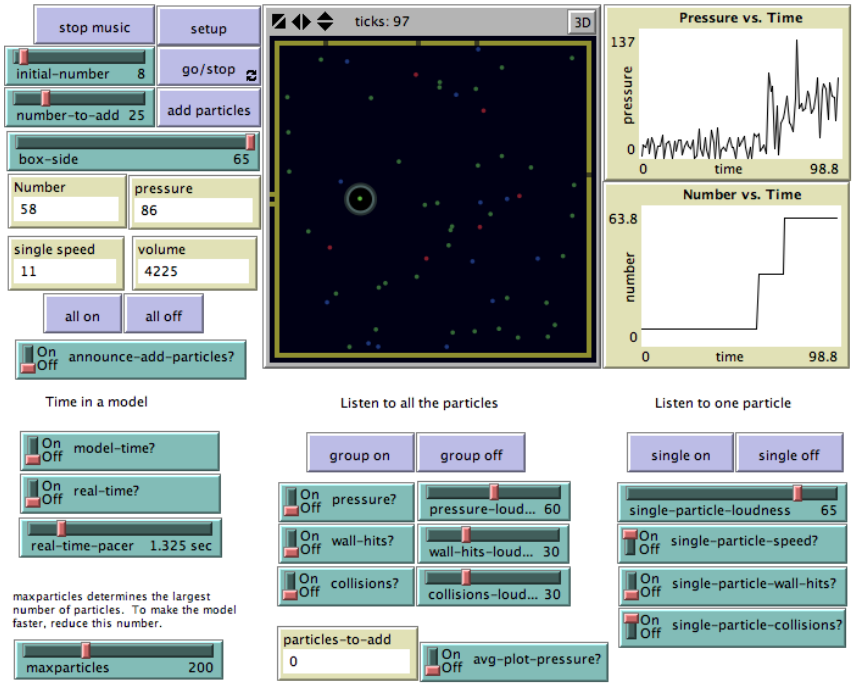


Figure 1. *User Interface.*

O Lahav, S T Levy, Listening to complexity: blind people's learning about gas particles through a sonified model, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 33–39, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Using augmented reality to support the understanding of three-dimensional concepts by blind people

C Kirner[1], T G Kirner[2], R S Wataya[3], J A Valente[4]

[1,2]Federal University of Itajubá,
Itajubá, BRAZIL

[3]Adventhist University of São Paulo,
São Paulo, BRAZIL

[4]State University of Campinas,
Campinas, BRAZIL

ABSTRACT

Seeing and describing real and imaginary three-dimensional scenes from the observer's viewpoint is an intuitive activity for non-impaired people, but it is difficult for congenitally blind people, once it involves abstract concepts for them, such as: perspective, depth planes, occlusion, etc. This paper discusses the problem related to understanding three-dimensional concepts by blind people and presents physical environments and procedures supported by an augmented reality tool in order to help blind people to understand, describe and convert three-dimensional scenes into two-dimensional embossed representations, like painting. To verify how the blind people can acquire those concepts, we developed an augmented reality application, working as an audio spatial tutor to make the perspective learning process easy. That application was tested with ten congenitally blind people, who understood the perspective concepts and made comments about the experience. Finally, we discuss the learning method and technical aspects, pointing out directions to improve the augmented reality application and ways to release it.

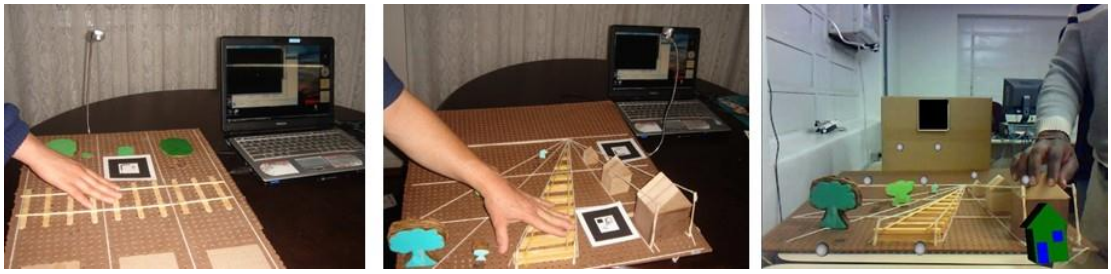


Figure 8. The *Audio Spatial Tutor in action.*

C Kirner, T G Kirner, R S Wataya, J A Valente, Using augmented reality to support the understanding of three-dimensional concepts by blind people, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 41−50, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Session II:
Visual Impairment

Augmented reality application for the navigation of people who are blind

J Sánchez, A Tadres

Department of Computer Science
University of Chile, Santiago, CHILE

ABSTRACT

A person who is blind can be capable of locating objects and also other people, such as a sighted person, by just using audio cues. In this research we present the design, development and evaluation of ARTAB, a technological assistant for people who are blind that uses Augmented Reality to identify a set of objects in an indoor environment. As a result, we generated audio-based representations that allow a user to determine the position of an object relative to the angle of vision of the video capture device for navigation purposes. The usability testing performed allowed us to detect that it is not trivial to assign sound effects so that the variation of such effects would imply changes in the position of an object. The continual variation of the sound pitch does not generate the contrast necessary for the blind user to be able to obtain a certain kind of information. However, users generally perceive ARTAB as a useful tool for assisting orientation and mobility tasks.

Figure 4. *Users who are blind utilizing ARTAB. A) The user focuses on the object that he wants to ask about, using neck and body movements. B) One member of our research team, in his role as the facilitator, analyzes what the user perceives through the system.*

J Sánchez, A Tadres, Visual tracking and audio-based interfaces for the navigation of people who are blind, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 51–60, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

PiTaSu: a wearable interface for assisting senior citizens with memory problems

T Kuroda[1], G Yamamoto[2], D Yoshitake[3], S Hickey[4], J Hyry[5], K Chihara[6], P Pulli[7]

[1]Department of Medical Informatics, Kyoto University Hospital,
54 Kawahara-cho, Sakyo-ku, Kyoto, JAPAN

[2]Graduate School of Natural Science and Technology, Okayama University,
3-1-1 Tsushima-naka, Kita-ku, Okayama, JAPAN

[3,6]Graduate School of Information Science, Nara Institute of Science and Technology,
89 16-5 Takayama, Ikoma, Nara, JAPAN

[4,5,7]Department of Information Processing Science, University of Oulu,
P.O. Box 3000, 90014, Oulu, FINLAND

ABSTRACT

Little research has been carried out on specialized wearable user interfaced designs to assist memory impaired senior citizens. This paper proposes and implements PiTaSu (Picture based Tapping on wall Surfaces) to realize direct user interface system to offer visual feedback and tactile feedback. PiTaSu is based on a pictorial based Augmented and Alternative Communication (AAC) system. PiTaSu consists of a body-worn or shoulder-attached mobile projector, a camera and an accelerometer wrist band. The projector shows information that will help assist the memory impaired senior citizen in their daily task. The camera and the accelerometer detect a tapping position and tapping trigger. Experimental results have demonstrated that a senior citizen can use PiTaSu without learning special skills, and the projection based user interface has potential. Therefore, PiTaSu can assist memory-impaired senior citizens as a daily task reminder.

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

Figure 4. *Detect finger-tip pointing position from outlier image. (a) one of outliner images, (b) the result of labelling operation, (c) the outlier's edge, (d) finger-tip pointing position.*

T Kuroda, G Yamamoto, D Yoshitake, S Hickey, J Hyry, K Chihara, P Pulli, PiTaSu: a wearable interface for assisting senior citizens with memory problems, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 61−69, Viña del Mar/Valparaíso, Chile, 31 Aug. − 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Designing an ecological virtual task in the context of executive functions: a preliminary study

X Cao[1], A-S Douguet[2], P Fuchs[3], E Klinger[4]

[1,4]Arts et Métiers Paristech - LAMPA, Angers-Laval, FRANCE

[2]Kerpape Rehabilitation Center, Ploemeur, FRANCE

[3]MINES ParisTech, Paris, FRANCE

ABSTRACT

Brain damage is a major cause of disability that often leads to deficits in executive functions with dramatic consequences on activities of daily living. While rehabilitation approaches of the dysexecutive syndrome are still limited, virtual reality has shown its potential to propose innovative intervention strategies based on ecologically valid functional tasks. The Therapeutic Virtual Kitchen (TVK) was designed as an assessment tool to help therapists and their patients with brain injury. In the TVK, some ecological virtual tasks may be configured by the therapists for patients' assessment and rehabilitation. The purpose of this paper is to validate the feasibility of the TVK with healthy subjects and patients with brain injury in Kerpape Rehabilitation Center.

Figure 1. *Kerpape real kitchen (left) and the TVK (right).*

Figure 2. *Four mouse visual cues.*

X Cao, A-S Douguet, P Fuchs, E Klinger, Designing an ecological virtual task in the context of executive functions: preliminary study, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 71–77, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Traumatic brain injury memory training: a virtual reality online solution

P Gamito[1,3], J Oliveira[1], J Pacheco[2], D Morais[1], T Saraiva[1], R Lacerda[2], A Baptista[1], N Santos[1], F Soares[1], L Gamito[1,3], P Rosa[1,4]

[1]Faculty of Psychology, University Lusófona of Humanities and Technologies, Campo Grande, 378, Lisbon, PORTUGAL

[2]Centre of Medical Rehabilitation of Alcoitão, Rua Conde Barão, Alcoitão, PORTUGAL

[3]Clinic of São João de Deus, Rua António Patrício, 29, Lisbon, PORTUGAL

[4]CIS, ISCTE/IUL, Avenida das Forças Armadas, Lisbon, PORTUGAL

ABSTRACT

This study aims at assessing an online portal where patients with traumatic brain injury (TBI) can carry on memory and attention exercises outside clinic premises. The training took place in a VR setup where one TBI patient had to complete a set of 10 online VR sessions. The neuropsychological evaluation was carried out with the PASAT (Paced Auditory Serial Addition Task) at pre, during and after treatment assessments. The results showed an increase in working memory and attention levels from the first to the final assessment, which can suggest that VR applications may promote the autonomy and increase in overall quality of life of these patients. The average time for task conclusion was of 5 minutes.

Figures 1-3. *Daily life activities; Working memory task; Visuo-spatial orientation task I.*

P Gamito, J Oliveira, J Pacheco, D Morais, T Saraiva, R Lacerda, A Baptista, N Santos, F Soares, L Gamito, P Rosa, Traumatic brain injury memory training: a virtual reality online solution, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 79−84, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Impact of the physical field of view on the performance in a purchasing task in the VAP-S for patients with brain injury

H Cherni[1], A Kadri[2], A Tarruella[3], C Le Roy[4], P A Joseph[5], E Klinger[6]

[1,2,6]Arts Métiers Paristech – LAMPA – EA 1427, Angers-Laval, FRANCE

[3,5]EA 4136, University of Bordeaux, FRANCE

[4]Kerpape Rehabilitation Center, FRANCE

ABSTRACT

In VR-based cognitive rehabilitation, there is a particular interest in subject's performance in the virtual tasks in which the patients are engaged. This performance is function of many factors among which the characteristics of visual information delivered by the virtual system. This study was designed to examine the impact of the physical field of view (PFOV) on the performance in a virtual task in the Virtual Action Planning Supermarket (VAP-S) among patients with brain injury and control subjects. Results show that, for all the participants, there is no significant difference between the main VAP-S variables in two experimental configurations (large FOV and small FOV), except for the number of incorrect actions that increases in the small FOV situation. We conclude in suggesting some explanations about the impact of the PFOV on patient use of the visual VAP-S information.

Figure 3. *The Virtual Action Planning Supermarket.*

H Cherni, A Kadri, A Tarruella, P-A Joseph, E Klinger, Impact of the physical field of view on the performance in a purchasing task in the VAP-S for patients with brain injury, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 85–91, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Participatory design with children with autism

L Millen, S V G Cobb, H Patel

VIRART, Human Factors Research Group, University of Nottingham,
University Park, Nottingham, UK

ABSTRACT

The COSPATIAL (Communication and social participation: collaborative technologies for interaction and learning) project explores how we can develop effective and useful educational technologies in the form of shared active surfaces (SAS) and collaborative virtual environments (CVEs) to support the enhancement of social skills for children on the autism spectrum. The UK design team comprises technology developers, design engineers, educational psychologists as well as teachers from both mainstream and autism specialist schools. A user centred design approach is used to make decisions and review prototype development using CVE technology. The team is then involved in detailed specification of CVE scenarios and iterative review of prototypes. The involvement of teachers throughout the entire process is crucial, but in order to understand the primary user further and implement concepts optimally it is also desirable to involve the target end users directly in the design process. This paper describes the participatory design approach for elicitation of user requirements and CVE scenario design that is being used with typically developing children and how these methods have been adapted to facilitate involvement of children on the autism spectrum.

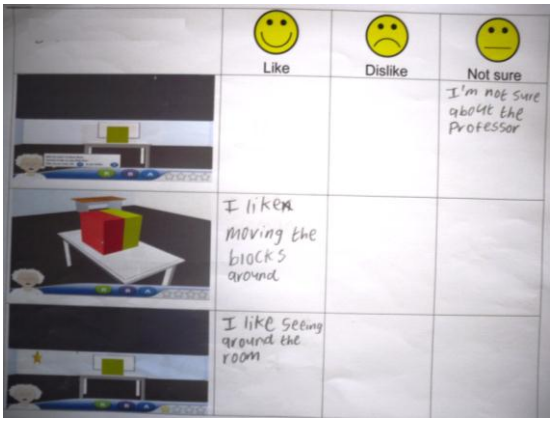


Figure 3. *Individual feedback worksheets used in prototype review with students with ASCs.*

L Millen, S V Cobb, H Patel, Participatory design with children with autism: the development of collaborative virtual environments, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 93–102, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

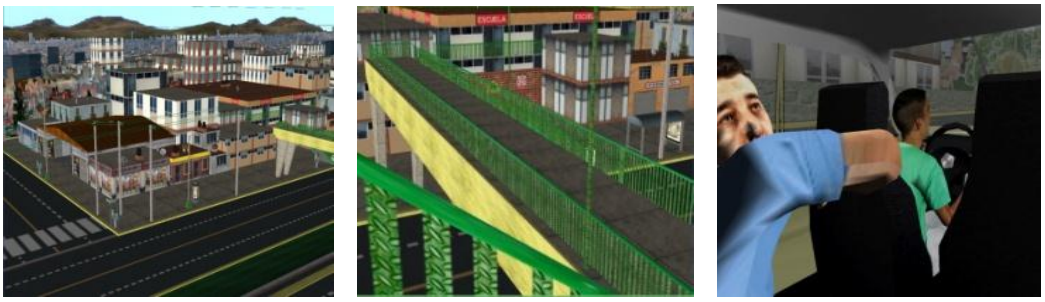
Post-traumatic stress disorder treatment with virtual reality exposure for criminal violence: a case study in assault with violence

A De la Rosa-Gómez, G Cárdenas-López

Virtual Teaching and Cyberpsychology Laboratory, National Autonomous University of Mexico
Av. Universidad 3004, Col. Copilco-Universidad Mexico City, MÉXICO

ABSTRACT

The criminal violence is attached with mental health problems as depression and substance use and abuse. However one of most important psychological problems linked with the victims of violence is post traumatic stress disorder (PSTD). In Mexico, according to the ENSI-5 in 2009, 11% (6,800/for each 100 thousands of habitants) of the population over 18 years, experienced a crime. One in four of the people victim of violence develops PSTD symptoms. Due to this socially relevant problem and based on the efficacy treatments, it is important to design treatments involving the use of Virtual Reality (VR), because it can help overcome some of the limitations of traditional therapy using exposure. The present paper expounds a case study of treatment program to PTSD in assault with violence.



Figures 2-4. *City view; Bridge view; Taxi view.*

A De la Rosa-Gómez, G Cárdenas-López, Post traumatic stress disorder treatment with virtual reality exposure for criminal violence: a case study in assault with violence, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 103–108, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Vital signs: quantitative measurement for phobias treatment with virtual reality

M Plaza Torres

Universidad Libre, Engineering Faculty, Bogotá, COLOMBIA

ABSTRACT

The level of the phobia condition and its progress is done by the evaluation that the doctor does of the patient, without having a control of the variables of measurement that show an indication of the medical evolution of the treatment. The possibility of identify variables that might be measured and of being able to determine the evolution of the patient and the level of the illness would be of benefit to medical discipline. The article talks about the efforts to carry out a research with the goal of measuring vital signs on people who are placed in a relaxed environment and then compare them with vital signs measured under condition of an artificial environment. At the end of this research, we are trying to determine if the virtual environment has any influence in the person's psychological change seen through the changes of the controlled vital signs.

Figure 2. *Virtual reality equipment.*

M Plaza Torres, Vital signs: quantitative measurement for phobias treatment with virtual reality, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 109–114, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Telehealth using 3D virtual environments in stroke rehabilitation – work in progress

J Broeren[1,3,4], L Pareto[2], C Ljungberg[2], B Johansson[1], KS Sunnerhagen[3], M Rydmark[4]

[1]Department of Research and Development, NU-Hospital Organisation,
SE-451 85 Trollhättan/Uddevalla, SWEDEN

[2]Laboratory of Interaction Technology, University West,
SE-461 86 Trollhättan, SWEDEN

[3]Institute of Neuroscience and Physiology, University of Gothenburg,
SU/Sahlgrenska, SE-413 45 Göteborg SWEDEN

[4]Institute of Biomedicine, Mednet, University of Gothenburg,

Box 420, 405 30 Göteborg SWEDEN

ABSTRACT

We have now started testing a telehealth system for stroke rehabilitation in a rural area in Sweden (NU- Hospital Group Area). For collection of assessments and audiovisual communication, the telehealth system has bidirectional contact with the home-based units. To date, three stroke subjects' participated; they were instructed to play 3D computer games with the hemiplegic upper extremity. The intervention led to clinical changes for all subjects. The analysis of the audiovisual communication revealed that the both stroke subjects and therapists were not yet effective in regulating their turn taking process. The data suggests the feasibility of a distance based approach using 3D virtual environments for upper extremity rehabilitation after stroke.

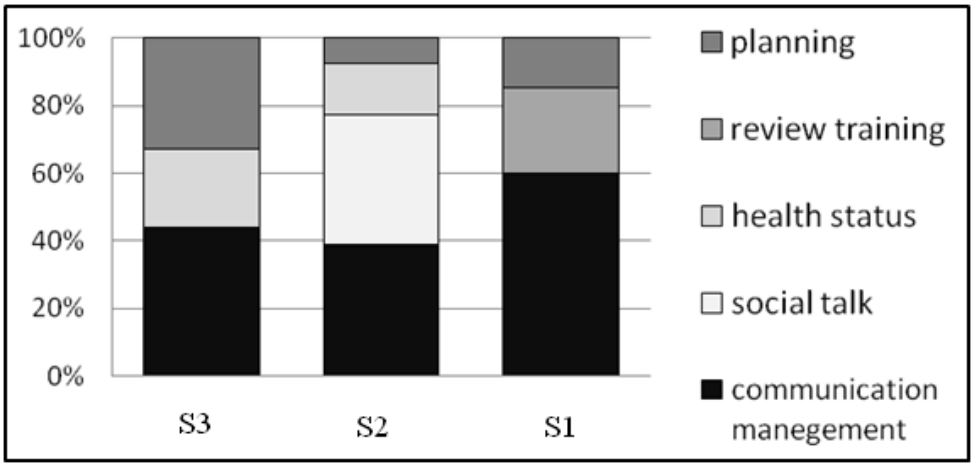


Figure 3. *Content analysis of the e-meetings.*

J Broeren, L Pareto, B Johansson, C Ljungberg, M Rydmark, Stroke rehabilitation using m-Health Care and 3D virtual environments – work in progress, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 115–122, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

A simple camera tracking virtual reality system for evaluation of wrist range of motion

D Shefer Eini[1,2], N Ratzon[1], A A Rizzo[3], S-C Yeh[3], B Lange[3], B Yaffe[2], A Daich[2], P L Weiss[4], R Kizony[2,4,5]

[1] Department of Occupational Therapy, Stanley Steyer School of Health Professions, Tel-Aviv University, Ramat Aviv, Israel

[2] Chaim Sheba Medical Center, Tel Hashomer, Ramat Gan, Israel

[3] Institute for Creative Technologies, University of Southern California, Marina Del Rey, CA, USA

[4] Department of Occupational Therapy, Faculty of Social Welfare& Health Sciences, University of Haifa, Haifa, Israel

[5]Department of Occupational Therapy, Ono Academic College

ABSTRACT

Clinicians assess wrist and hand function to identify pathology, monitor effectiveness of treatment, and determine the readiness to return to work and other activities. The goniometer, the conventional evaluation tool used to assess range of motion (ROM), is most suited to the measurement of passive and active joint ROM under conditions that entail static, non-functional movements. Instruments that measure ROM during complex, dynamic tasks may encumber the movement. We have adapted a simple optical tracking device that uses a low-cost webcam to track two diodes, referred to as the Virtual Wrist Tracker (VWT), to assess wrist ROM in 30 subjects, aged 18-65 years; fifteen patients had sustained orthopaedic injuries and 15 were control subjects. ROM was assessed by a standard goniometer and by the VWT under two conditions: visual auditory feedback and auditory pacing feedback. The results of test-retest analysis of control subjects demonstrated good reliability for the VWT during wrist extension and moderate reliability during wrist flexion. High, significant correlations were found between the ROM for wrist extension and flexion as measured by a goniometer and via the VWT in the research group and for wrist extension but not for wrist flexion in the control group. A repeated measures ANOVA mixed design showed no significant differences in wrist extension ROM or in wrist flexion ROM during the performance of the task with visual and auditory feedback versus a task with auditory pacing, nor was there interaction effects between task type and group during extension and flexion. Wrist ROM in either direction increased as the participant progressed from one target rectangle to the next; statistically significant interaction effect was found between ROM in target position and group indicating that the difference between the targets in the control group was significantly different than in the research group. Finally, both groups enjoyed performing the VWT tasks but the control subjects felt greater presence, success and control. The VWT appears to be a reliable and valid tool for assessing wrist ROM during dynamic activities.

D Shefer Eini, N Ratzon, A A Rizzo, S-C Yeh, B S Lange, B Yafa, A Dietz, P L Weiss, R Kizony, A simple camera tracking virtual reality system for evaluation of wrist range of motion, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 123–130, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Integrated arm and hand training using adaptive robotics and virtual reality simulations

A S Merians[1], G G Fluet[1], Q Qiu[2], S Saleh[2], I Lafond[2], S V Adamovich[1, 2]

[1]Department of Rehabilitation and Movement Science, University of Medicine and Dentistry of New Jersey, 65 Bergen Street, Newark, NJ, USA

[2,3]Department of Biomedical Engineering, New Jersey Institute of Technology, University Heights, Newark, NJ, USA

ABSTRACT

Virtual Reality simulations interfaced with robotic arm devices are being used for training the upper extremity of people post-stroke. The benefit has been hypothesized to be the ability to provide repetitive task practice, directed visual and auditory feedback, learning algorithms and graded resistive and assistive forces. All of these elements can be manipulated to provide individualized motor learning paradigms. We have developed a unique exercise system, interfaced with complex virtual reality gaming simulations that can train both the upper arm and the hand of people in the chronic phase post-stroke. After two weeks of intensive training, eleven subjects, were able to more effectively control the limb during hand interaction with the target as demonstrated by improved proximal stability, smoothness and efficiency of the movement path. This was in concert with improvement in the distal kinematic measures of fractionation and improved timing. These changes in kinematic measures were accompanied by robust changes in functional tests of upper extremity motor control, the Wolf Motor Function Test, the Jebsen Test of Hand Function and the 9-hole Peg Test.

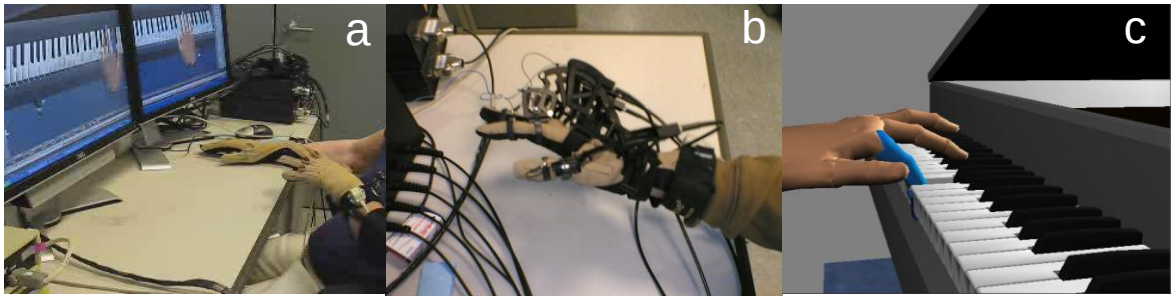


Figure 1. *(a).Picture of subject wearing a CyberGlove instrumented glove using the Piano Trainer Simulation; hands shown in a first person perspective. (b). CyberGrasp haptic device worn over a CyberGlove. (c).Picture of independent finger flexion as subject moves his hand to the cued key.*

A S Merians, G G Fluet, Q Qiu, S Saleh, I Lafond, S V Adamovich, Integrated arm and hand training using adaptive robotics and virtual reality simulations, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 131–138, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Study to evaluate a low cost virtual reality system for home based rehabilitation of the upper limb following stroke

PJ Standen[1], D J. Brown[2], S Battersby[2], M Walker[1,] L Connell[1] , A Richardson[3], F Platts[4,] K Threapleton[1], A Burton[2]

[1]Division of Rehabilitation and Ageing, University of Nottingham, Nottingham, UK

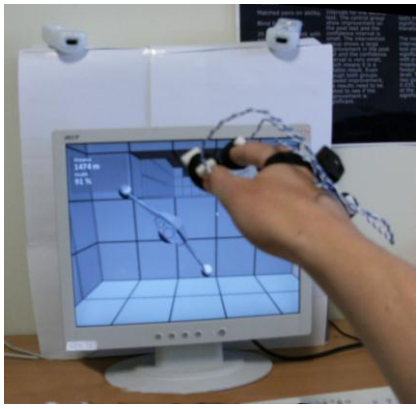
[2] Computing and Technology Team, School of Science and Technology, Nottingham Trent University, UK

[3] Erewash Community Occupational Therapy Service, Derbyshire, UK

[4] Nottinghamshire Community Health NHS Trust, Nottinghamshire, UK,

ABSTRACT

Stroke survivors with continuing impairment in their upper limb find it difficult to access the early intensive, task specific practice that research has shown is necessary for motor recovery. A systematic review of studies that investigate the effects of robot-assisted therapy on motor and functional recovery in patients with stroke found significant improvement in upper limb motor function but the systems reviewed are expensive, require technical support and are hospital or laboratory based. This paper describes the development of a low cost home based system together with a suite of games which would allow patients to practice the movements required for activities of daily living at the frequency required. The ongoing feasibility study is described.



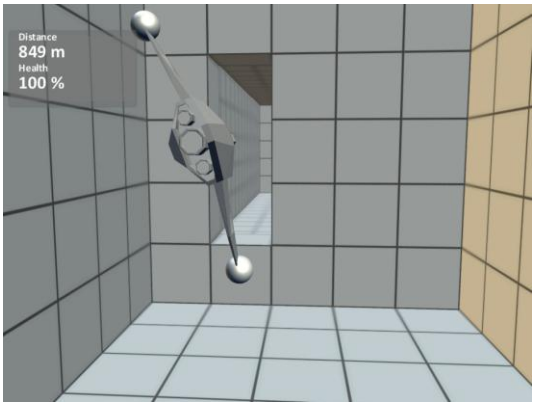


Figure 4. *Space race game showing player's hand position (left)***;**
Figure 5. *Screenshot of the space racegame (right).*

P J Standen, D J Brown, S Battersby, M Walker, L Connell, A Richardson, Study to evaluate a low cost virtual reality system for home based rehabilitation of the upper limb following stroke, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 139−146, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Remote monitoring and quantification of upper limb and hand function in chronic disability conditions

S H Brown[1], J Langan[2], K L Kern[3], E A Hurvitz[4]

[1,2,3]School of Kinesiology, University of Michigan,
1402 Washington Heights, Ann Arbor, Michigan, USA

[4]Department of Physical Medicine and Rehabilitation, University of Michigan,
325 E. Eisenhower Parkway, Ann Arbor, Michigan, USA

ABSTRACT

This paper describes a convenient, home-based telerehabilitation system designed to improve upper limb and hand function in adults with cerebral palsy. The training program incorporates a variety of computer-guided sensorimotor activities such as unilateral and bilateral reaching, reaching and grasping, object manipulation, and tactile discrimination tasks. Quantitative measures of performance are uploaded to the laboratory after each training session for further analysis. Webcam monitoring of performance occurs periodically throughout the training period. Twelve adults with cerebral palsy completed a 40 min/day, five days/week training program over eight weeks. Temporal measures of performance indicated significant improvement in reaching and hand manipulation ability as well as improved tactile discrimination. Preliminary analysis of the time course of change revealed variable patterns within and across participants. The capacity to measure change throughout a training program provides an opportunity to investigate how learning occurs over time in chronic disability. Compliance was excellent with subjective reports indicating improvement in activities of daily living. Future development includes a fully automated system with stand alone modules which allow for customization of training protocols depending upon specific needs of the user.

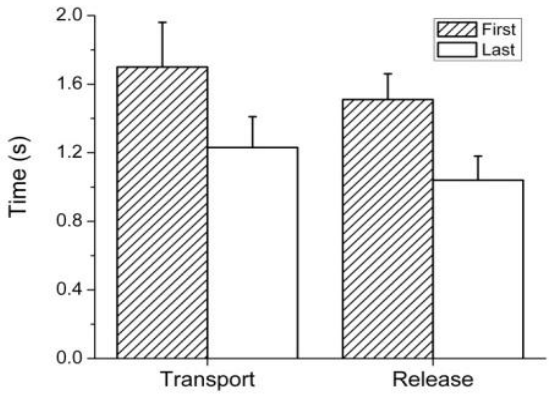


Figure 2. *Mean time required to reach, grasp and place an object (transport) and release and return to home position (release) during the first and last training session (more affected hand). Data are mean (+1 SE) for all 12 participants (p<.01).*

S H Brown, J Langan, K L Kern, E A Hurvitz, Remote monitoring and quantification of upper limb and hand function in chronic disability conditions, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 147–155, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Light Arrays: a system for extended engagement

D Wilde[1], A Cassinelli[2], A Zerroug[3], R J N Helmer[4], M Ishikawa[5]

[1,2,3,5]Ishikawa Komuro Laboratory, University Of Tokyo,
Hongo 7-3-1, Bunkyo-ku, Tokyo, JAPAN

[1]Department of Fine Art, Monash University,
900 Dandenong Rd, Caulfield East, Melbourne, VIC, AUSTRALIA

[1,4]Division of Materials Sciences and Engineering, CSIRO,
Henry Street and Colac Road, Belmont, Geelong, VIC, AUSTRALIA

ABSTRACT

We present the development vision of a range of interactive body-worn lighting systems for performance, play, rehabilitation and dis- or altered- ability support. The systems combine experimental and off-the-shelf technologies to arrive at outcomes that require and inspire extended physical and expressive engagement, and afford a range of different learning opportunities. We discuss the context and background, our aims and approach – mixing art, design and engineering methodologies. We then outline a number of scenarios of use and their relevance to ArtAbilitation. Our aim is to open up a dialogue with the ArtAbilitation community in the early stages, to generate collaborative interest and inform development.

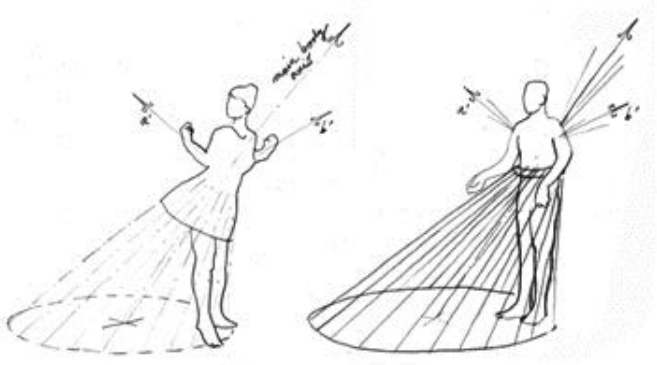


Figure 4. *In-visible garments for two – mapping movement and posture of one participant onto another participant's "skirt.*

D Wilde, A Cassinelli, A Zerroug, R J N Helmer, M Ishikawa, Light Arrays: a system for extended engagement, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 157–164, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Session VI:
ArtAbilitation

Warriors' Journey: A Path to Healing through Narrative Exploration

J F Morie, E Haynes, E Chance

Institute for Creative Technologies,
University of Southern California
12015 Waterfront Drive, Playa Vista, CA 90094, USA

ABSTRACT

The Warriors' Journey is an interactive narrative experience that is part of the online, virtual world healing space of the Coming Home Project (www.cominghomecenter.org) at the University of Southern California's Institute for Creative Technologies. This project is exploring new ways to reach veterans who are returning from recent conflicts and who often have mental health issues or difficulty fitting back into their home communities. We are looking at the affordances of online 3D virtual worlds to address some of the issues that may prevent or deter veterans from getting the help they need. We are exploring the use of specific therapies within the virtual world space, as well as social and enrichment activities designed around the needs of this group. *The Warriors' Journey* is one such activity that engages participants in stories to emphasize and reinforce common ideals of honorable warriors throughout history. After experiencing these stories, participants are then encouraged to construct their own warrior's story within the Coming Home space. It is hoped that such activities may help contribute to a more positive sense of self-esteem, a restructured life narrative, and a feeling of control over the stresses incurred during their service to their country.

Figure 1. *An image from the warrior's life.*

Figure 2. *The Story Tower structure.*

J F Morie, K Haynes, E Chance, Warrior's Journey – a path to healing through narrative exploration, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 165–174, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Extending body and imagination: moving to move

D Wilde[1], R J N Helmer[2], M Miles[3]

[1]Ishikawa Komuro Laboratory, University Of Tokyo,
Hongo 7-3-1, Bunkyo-ku, Tokyo, JAPAN

[1,2]Division of Materials Sciences and Engineering, CSIRO,
Henry Street and Colac Road, Belmont, Geelong, VIC, AUSTRALIA

[1,3]Faculty of Art & Design, Monash University,
900 Dandenong Rd, Caulfield East, Melbourne, VIC, AUSTRALIA

ABSTRACT

We present a range of body-worn devices that have evolved from a common design intent: 'to move the body through real and virtual extension'. These devices encourage people to move in extra-normal ways, and thereby view and experience their bodies from perhaps hitherto unknown perspectives. They provide a rich playground for self-expression, as well as learning opportunities that we believe might be relevant for people with physical challenges and unconventional or altered abilities. Our desire in presenting this work to the ArtAbilitation community is to open up a dialogue and examine opportunities for engagement.

Figure 4. *Light Arrays [Wilde, 2008].*

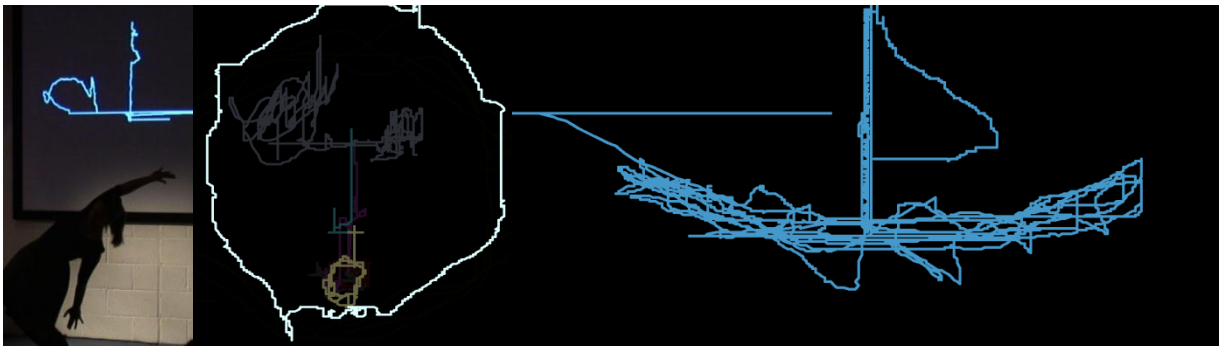


Figure 5. *hipDrawing and some hipDrawn images (2009) [Wilde, 2007-2011]*

D Wilde, R J N Helmer, M Miles, Extending body & imagination: moving to move, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 175–183, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Games for rehabilitation: the voice of the players

S M Flynn[1,2], B S Lange[1,2]

[1]Blue Marble Rehabilitation, Inc
Santa Rosa Ave, Altadena, CA, USA

[2]Institute for Creative Technologies, University of Southern California,
Fiji Ave, Marina Del Rey, CA, USA

ABSTRACT

The purpose of this study is to explore the use of video games from the perspective of the disabled player. Over 150 participants responded to an online survey exploring the use of video games for rehabilitation. The respondents represented 9 countries throughout the world. The survey consisted of questions regarding subject demographics, living situation, activities of daily living assistance requirements, use of assistive devices, and computer use. Other questions addressed the responders' disability. Video game play experience, activity, game play, controller use and accessibility are addressed. Questions regarding the use of currently available off the shelf video games in rehabilitation are explored. Lastly, we surveyed the future of video games and how they can be improved for rehabilitation and leisure enjoyment. The results of this survey are presented. In general, individuals with disabilities enjoy playing video games and play video games often. However, players with disabilities would appreciate educating the game industry about disabilities and how to makes games with a more "universal game design".

Table 3. *Ability to perform activities of daily living*

Pleaae tell us how you perform the following activities (choose all that apply)	I choose not to perform	Independently	with a device	with a personal assistant	I am unable to perform	Response Count
I feed myself	1	121	6	7	13	145
I bathe myself	1	99	3	31	13	144
I groom myself	1	106	6	23	13	145
I dress myself	1	101	1	33	14	145
I do my bowel routine	2	110	1	23	9	142
I do my bladder care	2	110	6	19	9	143
I use the toilet	3	110	2	15	17	145
I transfer from bed to chair	2	102	6	20	13	140
I am mobile on level surfaces	2	106	26	3	12	145
I am mobile on stairs	3	75	20	11	41	145

S M Flynn, B S Lange, Games for rehabilitation: the voice of the players, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 185–194, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Designing engaging, playable games for rehabilitation

J W Burke[1], M D J McNeill[1], D K Charles[1], P J Morrow[1], J H Crosbie[2], S M McDonough[2]

[1]Computing and Information Engineering, University of Ulster,
Cromore Road, Coleraine, BT52 1SA, UK

[2]Health and Rehabilitation Sciences Research Institute, University of Ulster,
Shore Road, Jordanstown BT37 0QB, UK

ABSTRACT

Stroke is a leading cause of severe physical disability and can result in of a range of impairments, including loss of balance, attention and concentration deficiencies, pain, weakness and paralysis. This paper reports on the design of serious games for upper limb rehabilitation following stroke. In particular, we focus on identifying principles of video game design which are important in the context of rehabilitation and show how these principles can be implemented. We also report on an evaluation of the games for playability, usability and engagement.

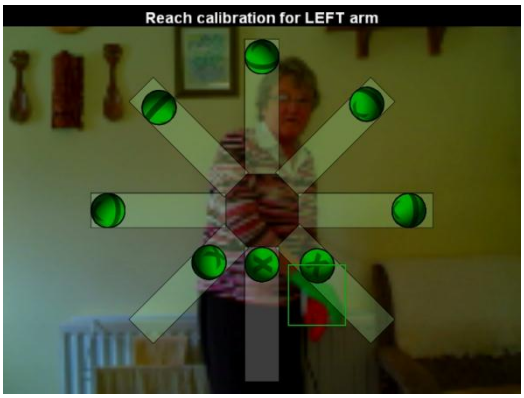


Image 1. *Range-of-movement configuration.*

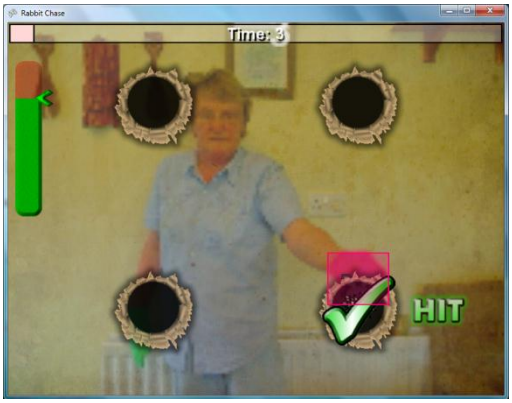


Image 2. *"Rabbit Chase", one handed game.*

J W Burke, M D J McNeill, D K Charles, P J Morrow, J H Crosbie, S M McDonough, Designing engaging, playable games for rehabilitation, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 195–201, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Session VII:
Games for Rehabilitation

Designing studies for the requirements and modelling of users for an accessible set-top box

P M Langdon[1], M F Gonzalez[2], P Biswas[3]

[1,3]Engineering Department, University of Cambridge,
Trumpington Street, Cambridge, UK

[2] INGEMA, Ingema Grupo Matia,
Camino de los Pinos, 20018, San Sebastian, SPAIN.

ABSTRACT

This paper describes work carried out to address the human centred design process behind the generation of requirements and user data for the prototyping of a user-model intended as part of a TV set-top box intended for use by mild to moderately impaired users. The aim is to develop both the technology and user modelling required within one STB system that will enable individuals with sensory, cognitive and physical impairments to interact with a number of reference applications. In order to do this it will be necessary for the system to categorise users on the basis of their input and interaction performance with a variety of input devices and assign them to a pre-assigned profile in the systems internal user-model. We address the issue of whether a human centred design process can be developed that is in principle capable of adequately generating the required data and specifications. We report the development of an inclusive design approach which subsumes both accessibility and usability. The ultimate aim will be to create a foundation for actual research and development work by identification of requirements from users as well as application and framework developers. We report the requirements analysis of this development and some preliminary results from user focus groups, chosen using an inclusive survey of capability, and interacting with early prototypes of interaction interfaces.

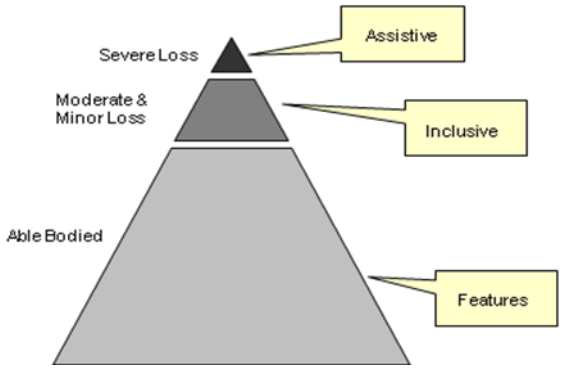


Figure 1. *The Inclusive Design Pyramid*

P Langdon, M F Gonzalez, P Biswas, Designing studies for requirements and modelling of users for an accessible set-top box, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 203–212, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Session VII:
Games for Rehabilitation

SimCoach: an intelligent virtual human system for providing healthcare information and support

A Rizzo[1], B Lange[1], J G Buckwalter[1], E Forbell[1], J Kim[1], J Williams[1], J Difede[2], B O Rothbaum[3], G Reger[4], T Parsons[1], P Kenny[1]

[1]Institute for Creative Technologies, University of Southern California
12015 Waterfront Dr., Playa Vista, CA., USA

[2]Weill Medical College of Cornell University
525 East 68th Street, New York City, N.Y., USA

[3]Dept. of Psychiatry, Emory University School of Medicine
1841 Clifton Road, NE, Atlanta, GA., USA

[4]National Center for Telehealth and Technology (T2)
9933 West Hayes Street, OMAMC, Joint Base Lewis-McChord, Tacoma, WA., USA

ABSTRACT

Over the last 15 years, a virtual revolution has taken place in the use of Virtual Reality simulation technology for clinical purposes. Recent shifts in the social and scientific landscape have now set the stage for the next major movement in Clinical Virtual Reality with the "birth" of intelligent virtual humans. This paper will present an overview of the SimCoach project that aims to develop virtual human support agents to serve as online guides for promoting access to psychological healthcare information and for assisting military personnel and family members in breaking down barriers to initiating care. While we believe that the use of virtual humans to serve the role of virtual therapists is still fraught with both technical and ethical concerns, the SimCoach project does not aim to become a "doc in box". Rather, the SimCoach experience is being designed to attract and engage military Service Members, Veterans and their significant others who might not otherwise seek help with a live healthcare provider. It is expected that this experience will motivate users to take the first step – to empower themselves to seek advice and information regarding their healthcare (e.g., psychological health, traumatic brain injury, addiction, etc.) and general personal welfare (i.e., other non-medical stressors such as economic or relationship issues) – and encourage them to take the next step towards seeking other, more formal resources if needed.

Figure 1. *SimCoach Archetypes – Female Aviator, Battle Buddy, Retired Sergeant Major.*

A A Rizzo, B S Lange, J G Buckwalter, E Forbell, J Kim, K Sagae, J Williams, J Difede, B O Rothbaum, G Reger, T Parsons, P Kenny, SimCoach: an intelligent virtual human system for providing healthcare information and support, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 213–221, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Development of an interactive stepping game to reduce falls in the elderly

B S Lange[1], S M Flynn[1], C Y Chang[1], W Liang[2], C L Chieng[2], Y Si[2], C Nanavati[2], A A Rizzo[1]

[1]Institute for Creative Technologies, University of Southern California, 12015 Waterfront Dr, Playa Del Rey, CA, USA

[2]Viterbi School of Engineering, University of Southern California, 3650 McClintock Ave, Los Angeles, USA

ABSTRACT

More than one-third of people over the age of 65 experience falls each year, and those who fall once are two to three times more likely to fall again. A fall can significantly limit a person's ability to remain self-sufficient. Fall injuries are responsible for significant disability, reduced physical function, and loss of independence. However, falls are not an inevitable result of aging. Systematic reviews of fall intervention studies have established that prevention programs can reduce falls. Physical activities, including strengthening exercises, tai chi, dancing and walking have been demonstrated to improve balance and decrease risk of falls in older adults. Modified dance-based exercises that include step-based movements have been demonstrated to improve endurance and balance in older adults. Dance video games, using a dance mat with areas that the player must step on in time with cues on the screen, have been demonstrated to improve activity and mood and reduce weight in children and youth. However, these dance games often include fast paced music, frequent jumping and an overload of visual information, movement and colors on the screen. This paper outlines the development of a prototype rhythm game that leverages the benefits of step-based exercise and dance video games to improve balance and reduce falls in older adults.

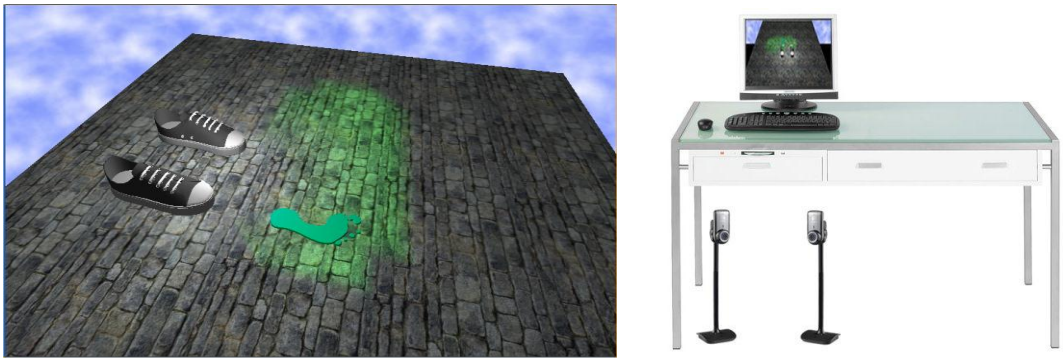


Figure 3. *a) Screen shot of game prototype, b) Set up of screen and cameras.*

B S Lange, S M Flynn, C Y Chang, W Liang, C L Chieng, Y Si, C Nanavati, A A Rizzo, Development of an interactive stepping game to reduce falls in the elderly, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 223–228, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

A virtual reality approach to gait training in service members with lower extremity amputations

S E Kruger

Walter Reed Army Medical Center
Washington, DC, USA

National Intrepid Center of Excellence
Bethesda, MD, USA

ABSTRACT

Gait training is an essential part of the rehabilitation process for those with lower extremity (LE) amputations. For service members at Walter Reed Army Medical Center, the Computer Assisted Rehabilitation Environment (CAREN) allows virtual reality to be incorporated into gait training as an adjunct to conventional therapies. This retrospective case series examines the self-selected velocities achieved in two different virtual environments (VE) by 11 service members with LE amputations. These VEs allowed participants to progress from level walking to more challenging terrain. Over periods of four to eight weeks, all participants were found to increase their self-selected velocities; progression appears to be individual. The preliminary results obtained indicate that further investigation is warranted.

Figure 1. *Participant walking on the CAREN system during the Continuous Road VE*

S E Kruger, Virtual reality approach to gait training in service members with lower extremity amputations, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 229–234, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Continuation of balance training for stroke subjects in home environment using virtual reality

I Cikajlo, M Rudolf, N Goljar, Z Matjačić

University Rehabilitation Institute, Linhartova 51, Ljubljana, SLOVENIA

ABSTRACT

The objective of the telerehabilitation is a continuation of the rehabilitation process on subjects' home and making the therapists and physicians possible to follow the progress remotely. Hereby the pilot project with virtual reality based tasks for dynamic standing frame supported balance training is presented. Six stroke subjects participated in the preliminary study. The subjects performed the therapy five times a week, each time for up to 20 minutes for three weeks. The results were evaluated by objective game parameters as track time, number of collisions and clinical instruments Berg Balance Scale, Timed Up&Go and 10m walk test. The outcomes demonstrated a significant improvement of all parameters. However, the follow up after two weeks demonstrated that functional improvement could be possible on a long term, if the subjects continue with targeted tasks for extended period of time. Besides, the balance training could be continued on subject's home instead of the hospital, which would decrease the number of outpatients' visits and reduce related costs.

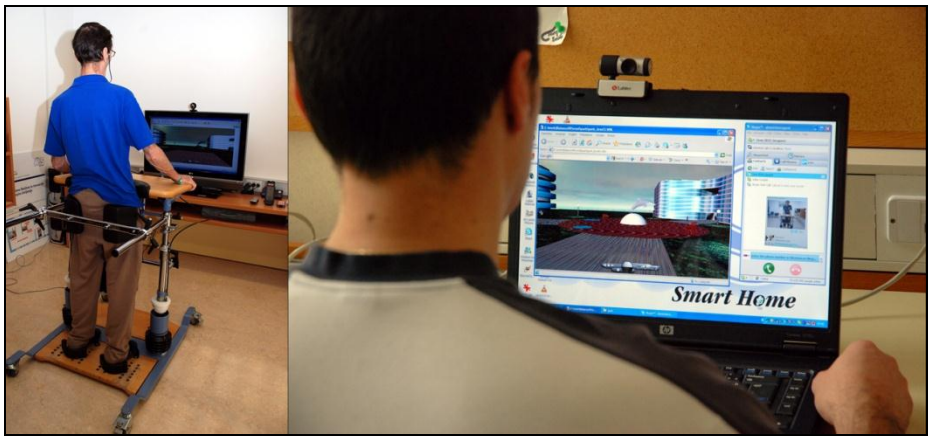


Figure 1. *Balance training with task in virtual environment could be continued on subject's home (left). Therapist (right) supervised and advised the subject through the videoconference and followed the task performance in the Internet Explorer.*

I Cikajlo, M Rudolf, N Goljar, Z Matjacic, Continuation of balance training for stroke subjects in home environment using virtual reality, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 235–240, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Audio-visual biofeedback system for postural control

M Milosevic, K M V McConville

Electrical Engineering Department, Ryerson University
350 Victoria Street, Toronto, M5B 2K3, Ontario, CANADA

ABSTRACT

This study presents an application of biofeedback in balance training, in particular an audio-visual balance rehabilitation system designed for training of the elderly. Motivated by the need to provide portable, cost-effective and accessible training devices, the system implements a MEMS accelerometer to quantify the balance board movements during a balancing task and use them to provide a real-time, synchronous audio-visual biofeedback. The visual feedback displays the offset and the overall performance of the balance board. The audio feedback is based on the sound localization cues that indicate the direction of the balance board movements using stereo sound. Initial results indicate a significant improvement in the postural stability when the audio-visual biofeedback is provided. The pilot study found significant improvements in maintenance and recovery of dynamic balance manifested through decreased variability of complex, lateral and front-to-back movements during a balancing task.

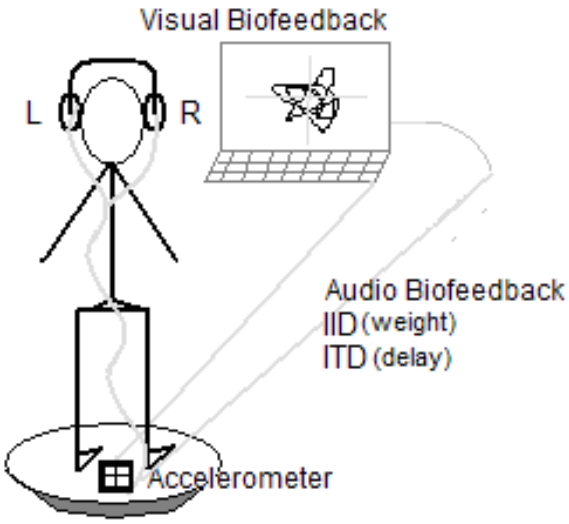


Figure 2. *System implementation for the audio-visual biofeedback. The subject is watching the visual display screen and at the same time receiving the stereo sound with the sound localization algorithm on the headphones.*

M Milosevic, K M V McConville, Audio-visual biofeedback system for postural control, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 241–247, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Development of an interactive rehabilitation game using the Nintendo® WiiFit™ Balance Board for people with neurological injury

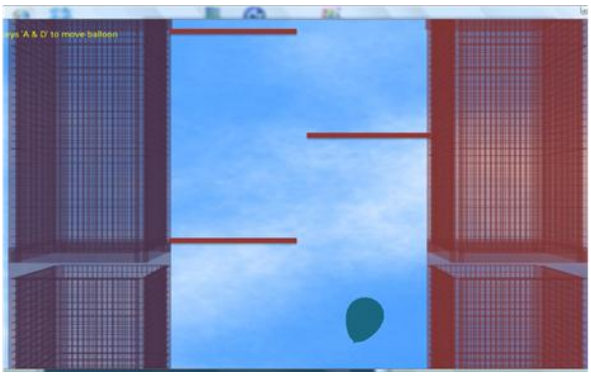
B S Lange[1], S M Flynn[1], C Y Chang[1], A Ahmed[2], Y Geng[2], K Utsav[2], M Xu[2], D Seok[2], S Cheng[2], A A Rizzo[1]

[1]Institute for Creative Technologies, University of Southern California, 12015 Waterfront Dr, Playa Del Rey, CA, USA

[2]Viterbi School of Engineering, University of Southern California, 3650 McClintock Ave, Los Angeles, USA

ABSTRACT

Visual biofeedback and force plate systems are often used for treatment of balance and mobility disorders following neurological injury. Conventional Physical Therapy techniques have been shown to improve balance, mobility and gait. The training program encourages patients to transfer weight onto the impaired limb in order to improve weight shift in standing and during gait. Researchers and therapists have been exploring the use of video game consoles such as the Nintendo® WiiFit™ as rehabilitation tools. Initial case studies have demonstrated that the use of video games has some promise for balance rehabilitation. However, initial usability studies and anecdotal evidence has indicated that the commercial games that are currently available are not necessarily suitable for the controlled, specific exercise required for therapy. Based on focus group data and observations with patients, a game has been developed to specifically target weight shift training using an open source game engine and the WiiFit balance board. The prototype underwent initial usability testing with a sample of four Physical Therapists and four patients with neurological injury or disease. Overall, feedback was positive and areas for improvement were identified. This preliminary research provides support for the development of a game that caters specifically to the key requirements of balance rehabilitation.



Figures 3 & 4. *Screenshots of second and third iterations of game.*

B S Lange, S M Flynn, C Y Chang, A Ahmed, Y Geng, K Utsav, M Xu, D Seok, S Cheng, A A Rizzo, Development of an interactive rehabilitation game using the Nintendo® WiiFit™ Balance Board for people with neurological injury, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 249–254, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Development of a voice-based rhythm game for training speech motor skills of children with speech disorders

D Umanski[1], D Kogovšek[2], M Ozbič[2], N O Schiller[1]

[1]Leiden University Centre for Linguistics, Leiden Institute for Brain and Cognition (LIBC), Leiden University, THE NETHERLANDS

[2]Department of Speech Therapy and Special Education, Faculty of Education, University of Ljubljana, SLOVENIA

ABSTRACT

In this project, we deal with the development and evaluation of a new tool for conducting speech rhythm exercises. A training methodology is proposed, based on a schedule of exercises, each presenting a sequence of syllables arranged in a specific rhythmic pattern. In order to assist the therapists with conducting speech rhythm exercises with children, we have developed a computer game prototype which implements the training, by providing the exercises, visual feedback and evaluation of performance. The game prototype was further evaluated in a usability study involving children with various speech disorders. We discuss the limitations of the current system and propose improvements for further development.

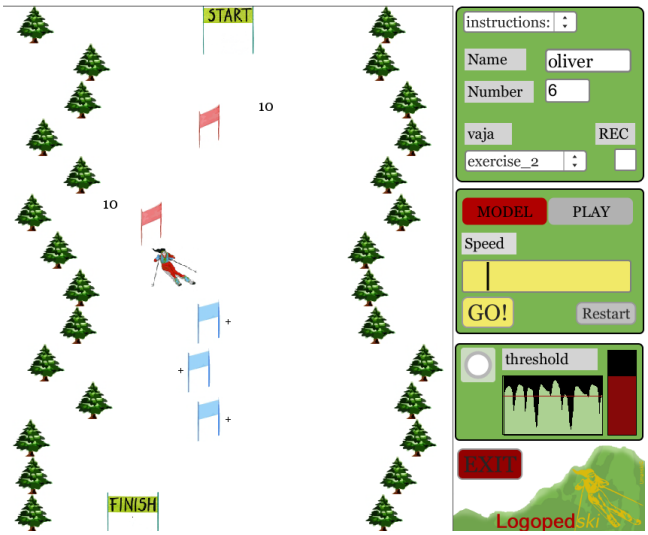


Figure 2. *A screenshot from the rhythm game prototype.*

D Umanski, D Kogovšek, M Ozbič, N O Schiller, Development of a voice-based rhythm game for training speech motor skills of children with speech motor disorders, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 255–262, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Robotic vocalization training system for the auditory-impaired

M Kitani, T Hara, H Hanada, H Sawada

Department of Intelligent Mechanical Systems Engineering, Faculty of Engineering,
Kagawa University, 2217-20, Hayashi-cho, Takamatsu-city, Kagawa, 761-0369, JAPAN

ABSTRACT

The authors are developing a vocalization training system for the auditory-impaired using a talking robot. The training system mainly consists of a talking robot which has mechanical organs like a human. With an adaptive learning strategy using an auditory feedback control, the robot autonomously learns the vocalization, and then reproduces the speech articulation from inputted sounds. By employing the talking robot, the training is realized by two different approaches. One is a training based on the hardware demonstration, which shows the speech articulation by the robotic motions, and the other is a software-based training, which shows the phonetic characteristics of generated voices. Training experiments are being conducted in Kagawa Prefectural School for the Deaf, and significant results have been obtained. In the previous system, the speech learning algorithm of the robot was constructed by using a Self-organizing Neural Network (SONN), which consists of the combination of a Self-organizing Map (SOM) and a Neural Network (NN). However, improper maps were found in the results of the speech articulation learning. In this study, a new algorithm using two SOMs, called a dual-SOM, is introduced for the autonomous learning of the robotic articulations. Firstly, the construction of the training system is described together with the autonomous learning of robotic vocalization using the dual-SOM algorithm, and then the analysis of the speech training progress is presented based on the phoneme characteristics and the mechanical vocal articulations.

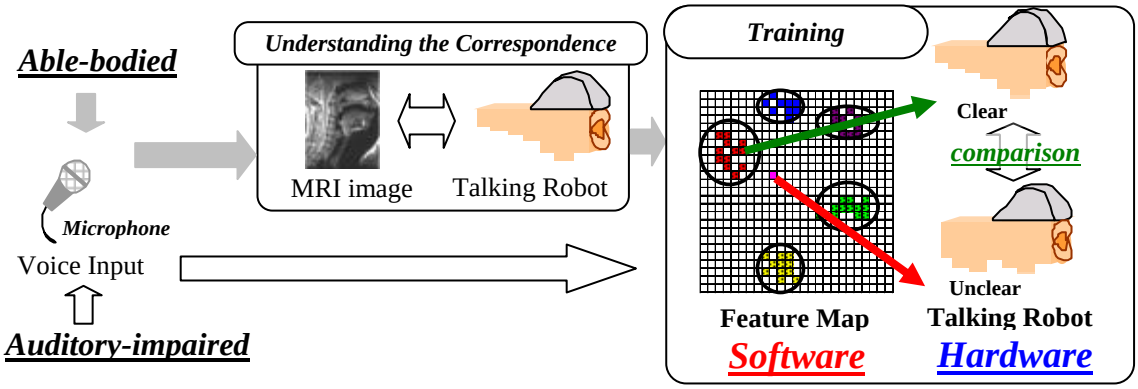


Figure 2. *Scheme of speech training system.*

M Kitani, T Hara, H Hanada, H Sawada, Robotic vocalization training system for the auditory-impaired, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 263–272, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Automatic speech recognition for assistive technology devices

A P Harvey, R J McCrindle, K Lundqvist, P Parslow

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

ABSTRACT

Speech offers great potential as a mode of interaction with devices to control our environment, support our work or assist us with tasks of daily living, however, to date the level to which this has been universally achieved and exploited has not matched its potential. Automatic Speech Recognition (ASR) is the process of interpretation of human speech by a machine. This may take two forms; continuous speech, as with human to human interaction or dictation, and discrete speech, such as commands issued to a device. ASR in the 'ENABLE' project uses discrete utterances to allow navigation of the user interface on a wrist worn device, control of the associated ECS (Environmental Control System) components as well as the ability to provide feedback for long term conditions using speech alone; features widely requested by users with a range of disabilities as well as by others for general ease of use. The aim of this paper is to explain the rationale and process behind the development of the ASR for the ENABLE device.

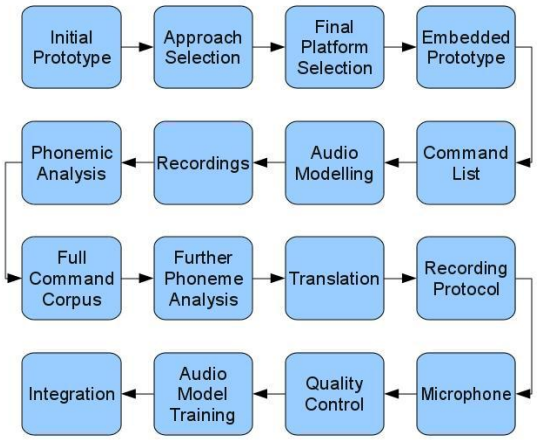


Figure 1. *Development Stages for the ENABLE ASR System.*

A P Harvey, R J McCrindle, K Lundqvist, P Parslow, Automatic speech recognition for assistive technology devices, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 273–282, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Session IX:
Speech & Audio

Basic study toward automatic generation of glove-type command input device with optimal number of sensors

Y Tabata[1], T Kuroda[2], K Okamoto[3]

[1]Department of Radiation Technology, Kyoto College of Medical Science,
1-3 Imakita, Oyama-higashi, Sonobe, Nantan, JAPAN

[2,3]Department of Medical Informatics, Kyoto University Hospital,
54 Kawahara-cho, Shogo-in, Sakyo-ku, Kyoto, JAPAN

ABSTRACT

Data-gloves are one of the most essential devices for VR systems. Although most of conventional data-gloves are designed to capture "analogue" hand postures, most of information systems require just "digital" hand postures corresponding to commands. This paper proposed a method to calculate a data-glove with optimal number of sensors to obtain given set of "digital" hand postures. The authors applied the proposed method to JSL. The result tells that a data-glove with just eight sensors can obtain all hand postures given in JSL.

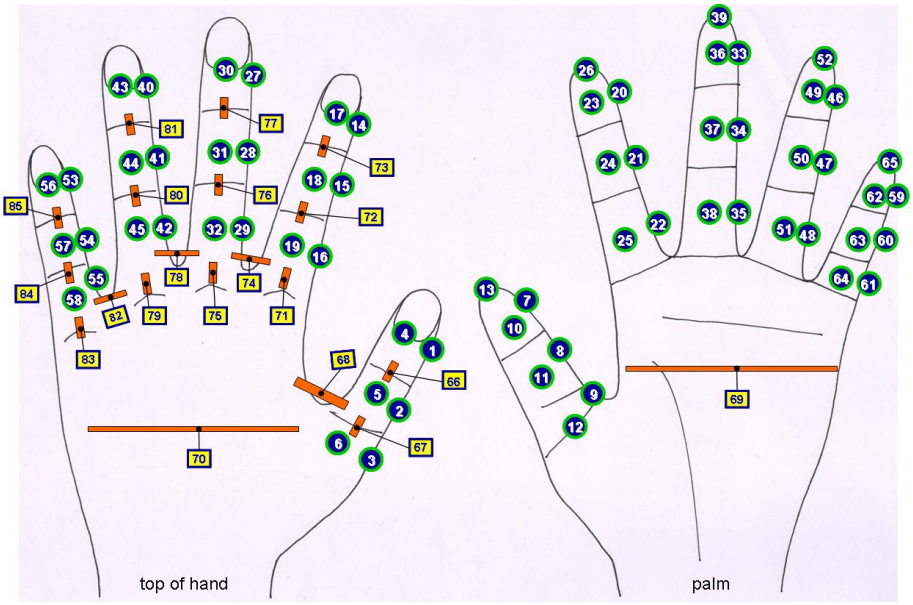


Figure 2. *Sensor Arrangement of Fully Furnished Data-glove*

Y Tabata, T Kuroda, K Okamoto, Basic study toward automatic generation of glove-type command input device with optimal number of sensors, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 283–289, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Poster Abstracts

Virtual environments for exposure in obsessive-compulsive disorder, **G Cárdenas López**, **S Muñoz**, Universidad Nacional Autónoma de México, MÉXICO

Obsessive Compulsive Disorder (OCD) affects 2.6% of the population in Mexico, severely affecting the quality of life of the people who suffer it. The World Health Organization (WHO) ranks OCD as the tenth leading cause of disability in the world, representing a health issue that requires attention, especially from health professionals. Several studies on the different treatments developed for this disorder have been carried, including: exposure, response prevention and cognitive therapy. We developed a treatment based on virtual reality (VR) technologies to expose patients with OCD to controlled virtual environments. The treatment includes sessions of psychoeducation, breathing training, cognitive restructuring and exposure, using a Head Mounted Display (HMD). VR increases the sense of immersion and presence in the environment, and evokes the same reactions and emotions that are experienced in real situations.

G Cárdenas López, S Muñoz, Virtual environments for exposure in obsessive-compulsive disorder, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 291–293, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Integrative approach for designing collaborative technologies for social competence training in children with autism spectrum conditions, **S V Cobb**, **L Millen**, **T Glover**, **S Parsons**, **S Garib-Penna**, **P L Weiss**, **E Gal**, **N Bauminger**, **S Eden**, University of Nottingham/University of Birmingham, UK and University of Haifa, Bar Ilan University, ISRAEL

The COSPATIAL project is exploring the use of two collaborative interaction technologies, Collaborative Virtual Environments (CVEs) and Shared Active Surfaces (SASs), as suitable media to support learning of social competence skills for typically developing children and those with Autism Spectrum Conditions (ASC)s. This paper describes the integrated approach used to design and develop learning scenarios in each technology.

S V Cobb, L Millen, T Glover, S Parsons, S Garib-Penna, P L Weiss, E Gal, N Bauminger, S Eden, M Zancanaro, L Giusti, Integrative approach for designing collaborative technologies for social competence training in children with autism spectrum conditions, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 295–298, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

Videogame for improving orientation and mobility in blind children, **J Sánchez**, **J P Rodríguez**, *Universidad de Chile*, *CHILE*

This work presents an evaluative study on the usability of a haptic device together with a sound-based videogame for the development and use of orientation and mobility (O&M) skills in closed, unfamiliar spaces by blind, school-aged children. A usability evaluation was implemented for a haptic device especially designed for this study (Digital Clock Carpet) and a 3D videogame (MOVA3D) in order to determine the degree to which the user accepted the device, and the level of the user's satisfaction regarding her interaction with these products for O&M purposes. In addition, a preliminary cognitive evaluation was administered. Usability results show that both the haptic device and the videogame are usable, accepted and considered to be pleasant for use by blind children. The results also show that they are ready to be used for cognitive learning purposes. Results from the preliminary cognitive study demonstrated significant gains in the development of tempo-spatial orientation skills of blind children when navigating in unfamiliar spaces.

J Sánchez, J P Rodríguez, Videogame for improving orientation and mobility in blind children, *Proc. 8th Intl Conf. on Disability, Virtual Reality and Assoc. Technologies*, P M Sharkey, J Sánchez (Eds), pp. 299–303, Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010.

©2010 ICDVRAT; ISBN 978 07049 15022

Exploring intelligent agents for controlling user navigation in 3D games for cognitive stimulation

R M E M Costa, D S Souza, I Mendonça

Departamento de Informática e Ciência da Computação
Universidade do Estado do Rio de Janeiro – UERJ,
Rua S. Francisco Xavier 524 – 6º B
20550-013 – Rio de Janeiro, BRASIL

rcosta@ime.uerj.br, diodss@hotmail.com, israel_mendonca@yahoo.com.br

ABSTRACT

Despite the many research efforts addressing the development of environments for Virtual Rehabilitation processes, only few of them consider a modeling step before system implementation. Our previous experience in developing virtual environments for stimulating cognitive functions stresses the necessity of adopting some Software Engineering practices. These open new possibilities to extend or integrate the system with others applications. The objective of this paper is to introduce some technical aspects related to modeling and implementing a multi-agent game for training memory and attention. We explore the integration of multi-agent model methodologies and present initial results of an experiment made with two specific languages for building three-dimensional virtual environments.

1. INTRODUCTION

Over the past few years, there has been an increasing amount of Virtual Rehabilitation research. In general, patients use these environments in sessions under the control of a therapist. However, due to growing demand, there is a need for environments that can be used by patients in their own home. At-home therapy allow in principle, better customization, more timely patient evaluation, and more access to care.. These environments must have an automatic control of the patients' evolution, simulating the therapist interventions. The emergence of Artificial Intelligence techniques opens new possibilities to support this process, exploring multi-agent systems.

Intelligent agents are able to have an adaptive and independent behavior, controlling tasks, interacting with humans, simulated objects and events (Wooldridge, 2009). These agents can be software entities embedded in the system or virtual characters in virtual worlds (Yang, 2008). Jennings (2002) considers that the agents work as assistants to users, supporting them to carry out tasks. In this context, several researchers, among them, Araújo et al. (2010), Bouchard et al. (2006) and Yang et al. (2008), used intelligent agents to increase the involvement of the user with the virtual environment (VE).

Despite the three-dimensional (3-D) virtual environments being frequently used in the neuropsychiatry, the use of intelligent agents for monitoring the patients' activities is rare. An example is the Grillon & Thalmann (2008) application that uses an eye-tracking system to control interactive virtual characters that change their behavior when being observed.

While VEs are recognized as an important tool for the rehabilitation, we need to study the impact of the integration of the new intelligent strategies in these environments. In this sense we must consider human as well as methodological and technical aspects.

The purpose of our study is to model and implement intelligent agents, integrating them with virtual 3-D environments. This paper discusses the necessity to consider some Multi-agent methodologies to create VE and presents initial results of an experiment that compares two different programming languages to construct 3-D virtual environments. Finally, we discuss several possibilities to test this approach with people with various neuropsychiatric disorders.

This work is organized into 6 sections. Section 2 gives an overview of the Virtual Reality in the rehabilitation area and Section 3 describes an experiment that explored the agent technology. Section 4

©2010 ICDVRAT; ISBN 978 07049 15022

presents the integration of agent modeling methodologies. In Section 5 the main characteristics of serious games for memory and attention stimulation are presented. Section 6 concludes the work and presents future research directions.

2. VIRTUAL REALITY FOR REHABILITATION

Virtual Reality includes advanced interface technologies, immersing the user in environments that can be actively interacted with and explored. The user can also accomplish navigation and interaction in a 3-D synthetic environment, using multisensorial channels. In this case, various types of stimuli can be transmitted by specific devices and perceived by one or more of the user's senses (Costa,2004) (Burdea and Coiffet, 2003).

Three-dimensional virtual environments present real-time graphics rendered by a computer, in which the user, via body position sensors or user-input devices, controls the viewpoint or the orientation of displayed objects (Pinho, 2002).

In the last few years, the potential of VE for the study and rehabilitation of human cognitive/functional abilities has been recognized. Therapy software aims to develop human capabilities and to reduce limitations, exploring different technical aids. The Virtual Reality and associated technologies provides opportunities to broaden physical and mental health applications, providing valuable scenarios with common elements for the patients, putting them in contact with daily life activities.

Recently, several experiments in this area describe case studies with positive results, which are stimulating new research that explore intelligent strategies (Dawson, 2008), (Broeren, 2008). However, in many applications there is a strong dependence on therapist's intervention to control the patient's navigation, to change the level of difficulty of a task, go back to an earlier stage, or control the order of activities in the synthetic environment. These interventions, however needed, cause distractions, reducing the level of user immersion in the simulation. As an alternative, the inclusion of intelligent agents could help to alleviate this problem, by reducing the need of therapist involvement.

3. INTELLIGENT AGENTS IN VIRTUAL ENVIRONMENTS

An agent is a software processes that are capable of independent action on behalf of its user or owner, without having to be told explicitly what to do in a given moment (Wooldridge, 2009).. An agent oriented paradigm reinforces the software flexibility and the agent's social possibilities, taking space as a solution in software engineering. Intelligent agents are used as software entities embodied in systems or as a virtual character that is part of the virtual world (Yang, 2008).

The use of an agent modeling methodology allowed the understanding of all the agents' features, as well as their communication processes. However, in general, the articles cited here do not mention the use of specific methodologies for modeling multi-agent systems. In order to fully take advantage of the opportunities offered by intelligent agents in VEs, we need to first understand how agents communicate and interact with each other.

In a perspective of educational use, there are some projects that explored intelligent agents for the support of users' learning. André et al. (1999) defined a framework for the development of presentation agents which can be utilized for multimedia help instructions. To control the agent behavior, the researchers used a decision tree and developed a declarative specification language to decide the agent behavior. The agents have a 2-D image and the objects they point to have a 3-D image. The researchers specified some pre- and post- conditions for each agent action. However, they did not mention any formal agent modeling methodology.

Johnson (2000) presented a system that has a life-like character which provides problem-solving advice in real-time, for learning environments. This work does not mention a formal methodology to model the agent behavior, but they developed a deictic model to combine the agents' speech, locomotion and gestures.

Pessin (2007) used a blackboard model to simulate the agents' conversation model. But, they do not stress any other methodology to model the agents' behavior.

Our research group developed a VE that has an Interface agent with a human-like appearance, to help patients accomplish some tasks in a kitchen (Cardoso, 2006). The system was modeled according to the precepts of the UML (Unified Modeling Language) with the definition of Use Cases, Sequence Diagrams and Description of Use Cases. The environment consists of a house with living room, two bedrooms, kitchen and

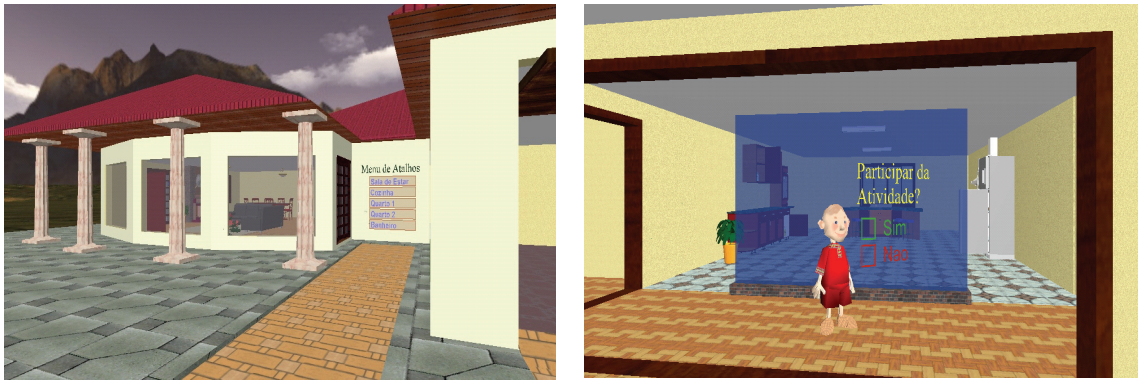
©2010 ICDVRAT; ISBN 978 07049 15022

bathroom. Each room provides cognitive stimulation activities. The interface agent (named "Bob") is in the kitchen, where he will support the accomplishment of tasks associated with activities of daily living.

When the user approaches the kitchen, the agent asks if he wants to attend an activity. If the user answers "Yes", the agent proposes to carry out a task: choosing the ingredients and utensils to make an omelet. The user must then open the fridge, click on the egg, open the cabinet and click on the pan, open another cabinet and click on the salt and oil. If the person misses some of these tasks, the agent speaks, giving tips and proposing an ingredient or utensil. If the user takes too long to make the decisions, the agent perceives the time delay and repeats the instructions, until the goal is reached.

The environment was developed in VRML (Virtual Reality Modeling Language) (Ames, 1997)). The functionality of the agent was implemented in JavaScript (JAVAScript,2010), which is the language that best fits VRML. The interface agent manages the tasks and decides what advice to give, from a decision tree, which considers the number of errors and the number of steps already taken on the task completion sequence.

Figure 1a presents the image of the house facade, showing a shortcut menu for users who have difficulty handling the computer mouse. Figure 1b shows the entrance to the kitchen, the agent Bob and a panel (with Portuguese text) where the patient must click to demonstrate their interest in participating in the activity.



(a) (b)

Figure 1. *Image of the facade of the house (a) and the entrance of the kitchen and the agent (b).*

After the first tests, we noticed that the behavior of the agent needed to be modified. However, since Bob's behavior did not involve modeling, it was difficult to make specific modifications, or integration with other environments. This problem led us to adopt a formal agent modeling methodology when authoring VEs containing intelligent agents.

4. MULTI-AGENT MODELING METHODOLOGY

The main purpose of the Multi-agent System Engineering (MaSE) methodology is to support the programmer in setting initial requirements and analyzing, drawing, and implementing a multi-agent system (MAS) (Gago, 2009). This methodology is independent of any agent's architecture, programming language, or communication framework. The MaSE treats the agents as a deeper object orientation paradigm, where the agents are object specializations. Instead of simple objects, with methods that can be invoked by other objects, the agents talk among themselves and proactively act in order to reach goals (Deloach, 2001), (O'Malley, 2001).

MaSE is a specialization of traditional software engineering methodologies with two phases (Analysis and Design) and several activities. However, the MaSE has some fragility to model the conversations between agents. For this reason we adopt some ADELFE (Atelier de Développement de Logiciels à Fonctionnalité Emergente) approaches.

According to Bernon (2003), ADELFE guarantees that the software is developed according to the Multi-agent systems theory. It follows the Rational Unified Process (RUP) (Jacobson, 1999) and uses UML (Unified Modeling Language) and AUML (Agent Unified Modeling Language) (Odell, 2000) notations. The interactions among agents and the user can be represented in the AUML Protocol Diagram, expressing how the system answers the end-user or the agents' requests.

Next, we present some characteristics of the games that have agents control the user's navigation.

5. GAMES FOR COGNITIVE STIMULATION

This research aims to verify the potential of intelligent agents in controlling the level of tasks offered to the user. If a user fails successively in performing a task he tends to feel discouraged. Moreover, a therapist intervention to reduce the task difficulty level can aggravate this situation, because patients can think that they are making many mistakes and feel insecure to answer. Therefore, if the software is able to perceive this weakness and automatically decrease the difficulty level of the exercises, the patient may have a decreasing level of frustration.

The environments have characteristics of serious games and aim to stimulate basic cognitive functions such as attention and concentration. They were built with JAVA3D (Java3D, 2010) and X3D languages (Brutzman, 2007) because these are free languages and offer good programming support and libraries. We constructed two similar scenes where the user must observe a geometric shape for a few seconds. It is presented in a frame on the wall. Afterwards the geometric shape disappears and three shapes appear on a table. Then user must choose the similar object among those on the table. The game has 4 difficulty levels and to change the level, the user must have 10 right answers in a row. When the level increases, the shapes can be duplicated or some colors can be redistributed to increase the degree of difficulty. However, if the user is having low success in choosing the right answers, the intelligent agents will decrease the difficulty level. To implement this control, the agents consider a combination of the number of correct/wrong answers, the time to choose an option, the task difficulty level and the results obtained in previous exercises.

In addition, to avoid common problems related to software product development, it is essential to have the support of procedures based on standards that ensure consistent results. Thus, the construction of VEs requires a process that considers the various steps involved and is appropriate to the peculiarities of Virtual Reality technology. We modeled the environments considering four phases: Requirements that identified the users, tasks and restrictions; Project, which defined software entities, the input and output hardware and modeling tools; the Implementing step made the integration of objects in the scene; and finally, the Assessment phase checks the performance, usability and value of the application.

To arrive to the third phase we made a detailed study of the JAVA3D language. This language offers various programming features and good portability that allows the visualization of virtual scenes in any browser. Figure 2 shows the main scene created with the JAVA3D language.

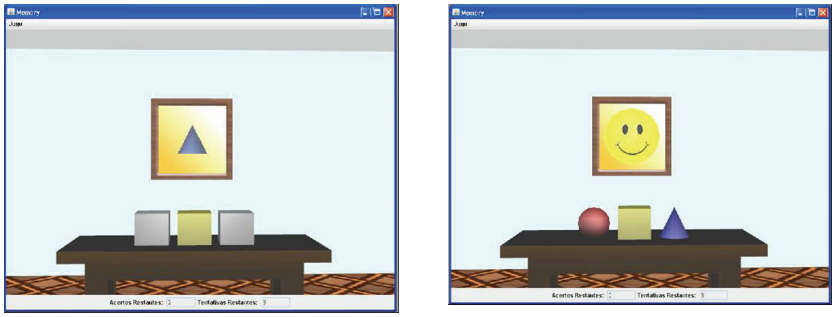


Figure 2. *Views of the game environment implemented in JAVA3D (JAVA3D, 2010).*

The X3D is an extension of VRML (Virtual Reality Modeling Language) (Ames,1997). The X3D combines geometric data and behavior descriptions in a Flash file that can have multiple transmission formats. Figure 3 shows a scene developed with X3D.

Initially, we studied different proposals for modeling intelligent agents, and authoring tools such as NetLogo tool and JADE framework (Wooldridge, 2009). However, these tools have proven inadequate for our purpose because they are not easily integrated with the JAVA3D and X3D. Then, we decided to use the structure provided by the languages, exploring the JAVA (JAVA, 2010) and JAVAScript (JAVAScript, 2010) languages, respectively.

Currently the agents are in the modeling phase. We are using the MaSE methodology (Multiagent System Engineering) (Deloach, 2001), which aims to support designers in the elicitation of the requirements set and its formal representation. For the agent communication model we are using the ADELFE AUML Protocols Diagram that express the way the agents answer an end-user's request.

©2010 ICDVRAT; ISBN 978 07049 15022

The agents will control the game to decrease the therapist's interventions, making it more comfortable for the patient. According to a preliminary experiment, we perceived that the applications have good possibility to improve the users' interaction with the environment.

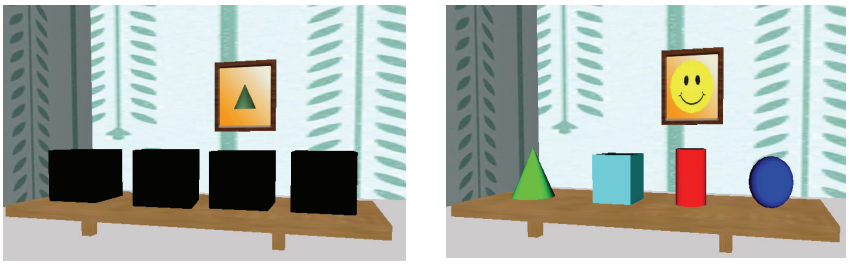


Figure 3. *View of the game environment implemented in X3D (Brutzman, 2007)).*

Until now, we realize that the JAVA3D has a small learning curve, because it uses the same structure as JAVA, such as library calls. The X3D language depends on learning a new language structure. JAVA3D is been more flexible to change the code and to integrate the multi-agent functionalities.

6. CONCLUSIONS

This paper discussed some technical questions related to the VE development process stressing the use of multi-agent approach to open new possibilities to users.

In 2000, the Brazilian Census showed that the number of people who declare themselves as having some kind of disability is around 24.5 million, approximately 14.5% of the population (Sarraf, 2000). These numbers show a high demand for treatment and social reintegration of these people. In general, the physiotherapy treatments are most commonly specified and used with the primary focus on motor rehabilitation. Commonly, the brain functions associated with cognition are neglected or receive a small amount of therapy in these treatments. To overcome this deficiency and make treatment more efficient, there is a growing movement to search procedures and practices which have as their primary purpose the reinclusion of these individuals in society and, by consequence, the minimization of their motor and cognitive disabilities.

Some types of exercises could be done at home, expanding the possibilities of rehabilitation. Thus, in this case, the virtual environment must have some kind of mechanism to control user navigation. This paper discussed some technical questions related to the VE development process, stressing the use of agent approach to open new possibilities to users.

The research described here as well as numerous studies going around the world indicate that virtual environments may be of great value in helping individuals, mainly when training them to live better in the real world. However, the use of Virtual Reality technology in cognitive rehabilitation merits further research to determine new development practices to increase access to care for a growing number of patients.

7. REFERENCES

A. Ames, D. Nadeau, J. Moreland (1997). *VRML 2.0 SourceBook*, 2nd edition, John Wiley & Sons.

E. André, T. Rist and J. Muller (1999), Employing AI methods to control the behavior of animated interface agents. *Applied Artificial Intelligence*; **13**, 4, pp. 415-448.

A. Araújo, L. A. Carvalho, R. M. E. M. Costa, (2010), The influence of intelligent characters on users' navigation through a three-dimensional Virtual Environment. *Presence: Teleoperators and Virtual Environments,* **19**, 3, pp. 253-264.

C. Bernon, M. P. Gleizes, S, Peyruqueou, G. Picard, (2002), ADELFE, a Methodology for Adaptive Multi-Agent Systems Engineering, *LNAI 2577*, P. Petta et al. (Eds.), pp. 156-169, Springer.

S. Bouchard, S. Dumoulin, G. Chartrand-Labonté, G. Robillard, P. Renaud, (2006). Perceived realism has a significant impact on presence, *Proceedings of the 11th Annual CyberTherapy 2006 Conference: Virtual Healing–Designing Reality*, Quebec, Canadá.

J. Broeren, A-L. Bellner, M. Fogelberg, O. Göransson, D. Goude, B. Johansson, P., Larsson, Pettersson, K., Rydmark, R., (2008), Exploration of computer games in rehabilitation for brain damage, *Seventh*

©2010 ICDVRAT; ISBN 978 07049 15022

International Conference on Disability, Virtual Reality and Associated Technologies, Maia, In: http://www.icdvrat.reading.ac.uk/2008/index.htm#abstracts-section-i, visited on may 2010.

D. Brutzman, L. Daly, (2007). *X3D: Extensible 3D Graphics for Web Authors,* Morgan Kauffmann.

G. Burdea, P. Coiffet, (2003). *Virtual Reality Technology*, 2nd Edition, Wiley, New Jersey.

L. Cardoso, R. M. E. M. Costa, A. Piovesana, M. Costa, M., Penna (2006). Using Virtual Environments for Stroke Rehabilitation, IEEE- 5th International Workshop on Virtual Rehabilitation, New York, pp. 1-5.

Costa, R. M. E. M., Carvalho, L., (2004). The Acceptance of Virtual Reality Devices for Cognitive Rehabilitation: a report of positive results with schizophrenia, *Computer Methods and Programs in Biomedicine*, **73**, 3, pp. 173-182.

A. Dawson, L. Buxbaum, A. Rizzo, (2008). The Virtual Reality Lateralized Attention Test: Sensitivity and validity of a new clinical tool for assessing hemispatial neglect, *Virtual Rehabilitation 2008*, Vancouver, in: http://www.virtual-rehab.org/2008/advanced_program.html, visited on march 2010.

S. A. Deloach (2001). Analysis and Design using MaSE and agentTool. *12th Midwest Artificial Intelligence and Cognitive Science Conference*, Miami University, Ohio.

I. S. Gago, V. M. B. Werneck, Costa , R. M. E. M. Modeling an Educational Multi-Agent System in MaSE. *Lecture Notes in Computer Science,* v. 5820, p. 335-346, 2009.

H. Grillon, D. Thalmann, (2008). Eye Contact as Trigger for Modification of Virtual Character Behavior, *International Conference on Virtual Rehabilitation*, Vancouver.

I. Jacobson, G. Booch, J. Rumbaugh, (1999). *The Unified Software Development Process* – Addison-Wesley.

JAVA (2010). In: http://java.sun.com/, visited on June 2010.

JAVAScript (2010). In: http://www.javascript.com/, visited on June 2010.

JAVA3D (2010), In: http://java.sun.com/javase/technologies/desktop/java3d/, visited on June 2010.

N. Jennings, M. Wooldridge, (2002). *Agent Technology: Foundations, Applications, and Markets*, Springer.

W.L. Johnson, J. Rickel, J. Lester (2000). Animated pedagogical agents: face-to-face interaction in interactive learning environments. *International Journal of Artificial Intelligence in Education,* **11**, 1, pp. 47-78.

S. A. O'Malley, A. Scott, S. A. Deloach (2001). Determining When to Use an Agent-Oriented Software Engineering Paradigm, Proceedings of the Second International Workshop On Agent-Oriented Software Engineering (AOSE-2001), Montreal, Canada, May.

J. Odell, H.V. Parunak, B. Bauer (2000). Extending UML for Agents, *Proceedings of the Agent Oriented* Information Systems (AOIS) Workshop at the 17th National Conference on Artificial Intelligence (AAAI), 2000.

G. Pessin, F. Osório, S. Musse, V. Nonnemmacher, S. S. Ferreira, (2007), Simulação Virtual de Agentes Autônomos para a Identificação e Controle de Incêndios em Reservas Naturais, *IX Symposium on Virtual Reality*, Rio de Janeiro, Brazil. (in portuguese).

M. Pinho, L. Dias, C. Moreira, E. Khodjaoghlanian, G. Becker, L. Duarte (2002). A user interface model for navigation in virtual environments. *CyberPsychology & Behavior,* **5**, 5, pp.443–449.

M. Rield (2001). A computational model and Classification Framework for Social Navigation, *Proceedings of the Intelligent Users Interfaces*, Santa Fé, pp.137-144.

M. Wooldridge (2009). *An Introduction to MultiAgent Systems*, John Wiley & Sons,

H. Yang, Z. Pan, M. Zhang, C. Ju (2008). Modeling emotional action for social characters, *The Knowledge Engineering Review*, Cambridge University Press, **23**, 4, pp. 321-337.

©2010 ICDVRAT; ISBN 978 07049 15022

Assessing navigation in real and virtual environments: a validation study

S T Koenig[1], G P Crucian[2], J C Dalrymple-Alford[3], A Dünser[4]

[1,4]HIT Lab NZ, University of Canterbury,
Private Bag 4800, Christchurch 8020, NEW ZEALAND

[1,2,3]Department of Psychology, University of Canterbury,
Private Bag 4800, Christchurch 8020, NEW ZEALAND

[1]*sebas@virtualgamelab.com*

[1,4]*www.hitlabnz.org,* [1,2,3]*www.psyc.canterbury.ac.nz*

ABSTRACT

For navigation ability, a transfer of knowledge from virtual training environments to real-world scenarios has been shown in several studies in the past. The purpose of this investigation is to demonstrate the equivalence of a series of navigation tasks in complex real-world and virtual buildings. Instead of testing knowledge transfer in very simple environments, identical tasks are performed in either version of a complex building. 29 participants are shown twelve landmarks, followed by a battery of tasks which are carried out in the real building by half of the participants, whereas the other half performs identical tasks in a virtual model of the same environment. No significant differences or effects were found, but due to the multifaceted nature of the gathered data and large variability within groups, overlap of both groups' distributions was minimal. To discover the underlying factors of this variability, further research is needed. Usability and future development of virtual environments are discussed.

1. INTRODUCTION

Navigation is a highly complex skill of moving oneself, a craft or vehicle through novel and familiar environments. A variety of cognitive functions such as memory, visual and spatial perception and problem solving are involved in this important skill. Without the ability to navigate, humans are highly restricted in their independent living. If any of the involved cognitive functions is affected by a brain injury, the amelioration of navigation deficits is an important part of cognitive rehabilitation. However, navigation training during rehabilitation is often restricted to very few locations like the hospital or the patient's home. When faced with such limitations it is desirable to use simulations to retrain patients' lost abilities in a wide range of environments. Whenever people have to navigate through inaccessible or dangerous environments, the simulation of such environments for training purposes is of large benefit. Until now, knowledge transfer between real and virtual environments (VEs) and differences between several modes of knowledge acquisation have been studied. The results of these studies have been mixed.

In a study by Richardson, Montello and Hegarty (1999) participants learned the layout of a complex building either from a map, the real building or a VE similar to the real building. Test performance in the real building yielded significantly poorer performance by the VE group. After multiple training sessions within a large-scale virtual building Ruddle, Payne and Jones (1997) were able to demonstrate near-perfect route finding abilities of their participants which closely resembled the real-world performance of a similar experiment by Thorndyke and Hayes-Roth (1982). Koh, von Wiegand, Garnett, Durlach and Shinn-Cunningham (1999) compared real-world training with the participants' exposure to immersive, non-immersive visualizations and also an architectural 3D model of the same environment. During training participants were free to explore the environment to their liking. While the authors conclude that training in virtual and real space are comparable, no actual navigation behaviour was required during the testing phase and only estimations of bearings and distances were reported.

Taken together, many virtual navigation studies have been limited in several ways. They either involve learning a single predefined route or only encompass judgements of bearings and distances from stationary viewpoints. This type of learning is valuable when demonstrating training effects from VEs to the real world, but is not sufficient for quantifying how people navigate through their surroundings. It is even less appropriate for making predictions of real-world navigation behavior which is desirable in a clinical context.

©2010 ICDVRAT; ISBN 978 07049 15022

Looking at predefined routes or knowledge of landmarks poses obvious restrictions on examining all of the behaviour which is involved in finding your way through a complex environment. Moreover, when people navigate in their daily life, their goals and priorities change often and unforseen circumstances and obstacles arise, so that a single predefined route is not always a viable solution. Routes cannot always be rehearsed in advance and the navigator has to make inferences about alternative routes and the overall spatial layout of the environment. Assessing such configurational knowledge about the environment in addition to route knowledge is a step in the right direction. Witmer, Bailey and Knerr (1996) trained their participants in a complex office building and assessed route and configurational knowledge. However, their study is still limited to a predefined route and landmarks along that route. The authors' results suggest that using VEs for route learning is superior to maps, but inferior to real-world training. Configurational knowledge was unaffected by different learning media.

Examining navigation behaviour in all its complexity, this present study is explicitly comparing human navigation in a large real-world building and its virtual counterpart. The quantification of navigation behaviour is part of a planned framework for training, assessing and eventually predicting cognitive skills in a clinical context, with focus on patients with brain injuries. With such focus it becomes important to assess how and why people are getting lost, as it is the case with brain-injured individuals. Thus, an important aspect for this study's design is the high demand which is placed on the participants' navigation skills to provoke situations of temporary disorientation. The developed virtual reality simulation is intended for use in the day-to-day routine in rehabilitation settings. As such, usability, flexibility and compatibility with the needs of brain-injured individuals are of highest importance and are discussed in the context of the development cycle of such a VE. To satisfy the needs of clinicians, several navigation parameters which are relevant for predicting a patient's performance outside of the rehabilitation hospital are being analyzed. Lastly, it is hypothesized that those critical parameters of navigation ability - namely walked distance, received cues, amount of decision errors at intersections, distance estimations and pointing errors - are similar in complex real and virtual environments. The navigation time, the number of stops a participant makes and the total time spent standing still during navigation are predicted to be higher in the VE, as these variables are expected to be influenced by the VE interface.

2. METHODS

2.1 Participants

36 healthy, right-handed participants from the Christchurch community aged 40 or above and unfamiliar with the tested building volunteered for this study. Only 29 participants are included in the analyses as three participants withdrew from the study due to symptoms of simulator sickness, two participants were familiar with the tested environment and two participants were excluded due to missing data after a technical failure of a recording device. The specific age group was chosen to include users with a wide range of computer experience and to assess the age bracket of patients with stroke who are expected to be a primary target group of the developed navigation assessment in the future. Age of the participants ranged from 51 to 72 years in a real-building group while the age for a VE group ranged from 42 to 66 years. Male and female participants were equally assigned to both groups – six male and nine female participants in the real-building group and five male and nine female participants in the VE group. None of the participants reported playing computer games apart from non-spatial puzzles or card games.

2.2 Design

Participants were assigned to either a real-world or VE group in a randomized blocked design. Each participant was shown the same set of 12 target locations within the real version of a complex building on campus of the University of Canterbury, New Zealand. Following the initial learning phase, a series of pen and paper tasks for assessment of spatial abilities were completed. Finally, half of the participants returned to the real building to find the previously shown locations while the other half was asked to complete the same tasks in the virtual version of the campus building.

2.3 Materials

2.3.1 Real and virtual environment. The assessed environment is the seven-floor Erskine Building at the University of Canterbury, New Zealand. The building was chosen for its complexity and unusual layout with a combination of large open space and narrow corridors. Only the lower four of all seven floors were used for the assessment. A floor plan with targets for the first floor can be seen in the appendix. The four included floors differed substantially in regards to corridors, smaller staircases and landmarks. Several staircases throughout the building allowed for a large amount of possibilities to traverse from one landmark to the next.

©2010 ICDVRAT; ISBN 978 07049 15022

The virtual model of the building was created using Google SketchUp 7 Pro. Textures were imported from photographs and floor plans were used to model the building to scale. Floor plans and measurements were displayed with Autodesk Design Review 2011. Most exit signs, direction signs and details within the building were included in the model with the goal of incorporating all constant features into the VE. Unfortunately, some minor aspects of the building change often so that not all details were up-to-date in the assessment. Interactions within the VE, data collection, interface and visual and navigation analysis tools were developed with the game engine Unity (version 2.6). The finished application records position and rotation of the participant within the VE in intervals of 100ms. The virtual environment was displayed using a three-screen back projection system with a field of view of 180 degrees. However, due to technical limitations only 120 degrees of the environment were displayed on screen so that the left and right edges on screen appeared slightly stretched. Each screen measured 2.44m x 1.83m. The participant was seated 2.2m in front of the center screen. This set up allowed the participants to show natural orientation behavior by turning to the side screens for searching the environment. The VE was rendered using a single PC with a quad-core CPU and three Nvidia GeForce GTX260 graphics cards running in SLI. All six projectors received input from two Matrox Triple-Head2Go graphics expansion modules. Only three of the six projectors were used to provide a non-stereoscopic rendering of the VE. This was done to allow the large interactive environment to run at a steady frame rate of 80 frames per second. Participants used a standard three-button computer mouse to navigate through the environment. Mouse movement was implemented to correspond to left-right and up-down head rotation and holding down right or left mouse buttons moved the participant back and forth at walking speed respectively. Sensitivity of the mouse was reduced substantially when compared to first-person computer games to allow participants with no computer experience to use the mouse accurately.

2.3.2 Pen and paper tests. Spatial abilities were measured with the Object Perspective Taking Test (OPTT; Hegarty & Waller, 2004), Mental Rotations Test (MRT; Vandenberg & Kuse, 1978) and the Card Rotations Test (CRT; Ekstrom, French, Harman & Dermen, 1976). In addition, orientation ability was assessed with the Santa Barbara Sense of Direction Scale (SBSODS; Hegarty, Richardson, Montello, Lovelace & Subbiah, 2002). Simulator sickness was assessed using the Simulator Sickness Questionnaire (SSQ; Kennedy, Drexler, Berbaum & Lilienthal, 1993). Computer experience was measured with an adapted version of the Computer/Internet Experience and Skills Questionnaire for: Internet Diabetes Trial at Harborview (Goldberg, 2004).

The OPTT is a test for spatial ability which requires judgements of bearings from imagined viewpoints. The test's score is the average of the absolute deviations from the correct angles over all of the test's twelve items. The MRT consists of three-dimensional line drawings (target) which need to be compared to four test objects. Two of the test objects are rotated versions of the target which need to be identified. The other two are mirror images or of slightly different structure. The test consists of 20 items, four test objects each, and the score is calculated by the number of attempted test objects divided by the number of correctly identified test objects. The CRT also requires the correct identification of test objects in comparison to a target object. However, the test and target objects are random polygons in different two-dimensional orientations. The number of attempted test objects divided by the number of correctly identified test objects is used as the test's score. Lastly, the SSQ assesses the severity of a range of symptoms of simulator sickness. This self-report measure states 16 symptoms for the domains of "nausea", "oculomotor" and "disorientation". The participant is asked to rate each symptom as either "none", "slight", "moderate" or "severe".

2.3.3 Navigation Test. Navigation through the Erskine Building consisted of two phases. During an initial learning phase, all participants were guided through the building on a predefined path which passed 12 target locations on four different floors. Four locations in the basement (Lecture Theater, Crypt Room, Bluebird Vending Machine, Dead End) and first floor (Main Entrance, Reboot Cafe, Coke Machine, Elevator) and two locations on second (Reception, Atrium Bridge) and third floor (Seminar Room, Walkway) were chosen. The total length of the walked training route is 498 meters. The walking distance was determined during a test trial in the VE which provided accurate measurements of the route. The lower four floors contain a total of 26 decision points where participants must choose between alternate paths. The basement contains three points, first floor contains four points, second floor contains eight points and third floor contains eleven points. Alternate paths are classified as either optimal, suboptimal or wrong. Unfortunately, there is no established way of classifying paths through a complex environment. With such a large amount of possible paths for each task, a simple dichotomy of correct or wrong paths does not capture all information. The following classification appeared to unambiguously classify each of the participant's decisions, no matter how complicated the taken path was.

- The optimal path is defined as the shortest single route which takes the participant from start to target.

©2010 ICDVRAT; ISBN 978 07049 15022

- A wrong path is a decision which leads towards a wrong floor (i.e. target is up but participant goes down), along a route which does not lead to the target at all (i.e. dead end or wrong room) or any decision which is a direct turnaround on a path which leads optimally or sub-optimally to the target. That is, if the participant is standing very close to the target and has the optimal or suboptimal path ahead, but incorrectly turns around and retraces the previously walked path, this is considered wrong.
- All chaotic movement which cannot be classified as walking a defined path, but rather involves walking back and forth, in circles or any other diffuse behaviour, is considered an additional wrong decision.
- All remaining path choices are evaluated for the travel distance they require to reach the target, assuming that all following path choices minimize travel distance. The shortest of these paths is suboptimal, all others are wrong. If two or more are of the same shortest length, they are defined to be suboptimal. This is especially common in buildings with symmetrical layouts.

Optimal decisions were analyzed separately whereas suboptimal and wrong decisions were combined to an error score. Suboptimal decisions were scored as an error with a factor of one and wrong decisions were scored with a factor of two. The error score is the sum of all non-optimal decisions.

Half of the twelve target locations were secluded and allowed no direct line of sight to the other locations whereas the other half was in a more central location with higher visibility towards other locations and the layout of the building. This selection was based on the approach of Braaksma and Cook (1980) who evaluated the complexity of large buildings using a line-sight-network where visibility between all important landmarks within a building was assessed. This approach was applied to the seven-floor Erskine building to quantify the difficulty of each target location. However, the classification of target difficulty and its influence on navigation behavior is beyond the scope of this paper and will be discussed elsewhere. It was also not possible to control the order and amount of exposure that each location received during the initial learning route in such a complex environment. Though, the hidden locations naturally received less exposure whereas the central locations were seen more often during route traversal. Before walking along the learning route the participant was instructed to pay attention to the target locations and more importantly, to get a good sense of the overall layout of the building. Instructions also included the fact that the traversed learning route and order of target exposure were irrelevant for the following navigation test. Further, it was mentioned that all target locations were again to be rehearsed before starting the navigation test. Participants were not allowed to wander and had to stay with the experimenter at all times. Walking speed along the route was held constant as far as that was subjectively possible by the experimenter. Though, the participants were allowed to stop along the route and look around. Orientation behavior was strictly encouraged and initial instructions emphasized that the participant was free to do what he/she normally does when being in a novel environment. While questions were not forbidden, the only provided answer was the floor which the participant was currently on. Instructions and explanations about floors and target locations along the route were identical for each participant. Lastly, each target location was accompanied by a so-called reference point. In order to accurately point or navigate to the target during the test trial, an exact location was given to the participant (e.g. center of Coke Machine, middle of Elevator).

For the assessment phase of the study a different order of target locations was chosen to avoid the usage of the learning route. For the same reason the building was entered through a different entrance. Participants were expected to demonstrate configurational knowledge from the very beginning of the assessment by finding new ways through the building. Half of the target locations were designated navigation targets while the other half was used for pointing tasks. Order and nature of tasks was the same for all participants and both groups. Navigation and pointing tasks were always alternated.

For navigation tasks participants were instructed to find the shortest way to the given target without using elevators or asking other people for help. There were no route restrictions and all of the lower four floors were available for use by the participants. Cues were given systematically whenever participants asked for help or indicated that they were lost. Further, whenever a participant took more than 2 consequent wrong turns at a decision point or when no progress was made on a wrong floor (>4 decision points without leaving the floor towards the correct floor), a cue was given. Cues were categorized to either state that the participant is on the wrong floor, to verbally identify the correct floor, to give a semantic cue about the target (what the target looked like), to guide towards the correct side of the building, to name the reference point and to cue everything (explain in detail how to get to the target). Cues were given gradually in the listed order except when a participant asked specifically for a cue (e.g. “Which floor is the target on?”). Participants’ navigation performance in the real building was recorded on video. All videos were later analyzed using VirtualDub to extract the timing of all tasks, cues, stops and to plot the exact route on a floor plan using Autodesk Design Review 2011. Performance in the VE was automatically recorded as described above. In addition, the plotted

©2010 ICDVRAT; ISBN 978 07049 15022

paths on the floor plans were later rewalked in the VE with accurate timing and route to utilize the strengths of the VE to visualize and analyze the data. That is, by transferring all data into the VE, distances, number of stops, angles and viewpoints were easily computed, compared and displayed in 3D space with pinpoint accuracy. While measurements in the VE are accurate to about 2-3mm, transferring the video-recorded navigation data onto the floor plan and into the VE was done manually. Thus, location errors of up to 30cm and timing errors of up to half a second per stop are to be expected. For visual and computational analysis of the participants' routes, the original VE was modified using the Unity game engine to allow the experimenter to visualize all data, rewalk routes and carry out distance and angular calculations after the experiment was finished. The participant's route was plotted by a large number of data points which represented location and rotation data within the VE at a given time. Data points were rendered as simple sphere objects in the VE and were identified by a time stamp to follow the participant's route visually and chronologically.

Pointing tasks were given whenever the participant reached a navigation target. As soon as a target was reached, a tripod with an attached protractor was set up at a predefined location. The tripod had a wooden plate mounted on top with a clock-hand attached to it. The protractor was hidden underneath the wooden plate to prevent giving any cues to the participant. The clock-hand was used by the participant to indicate the direction in which the pointing target was expected to be. The protracter indicated the angle in which the participant pointed. The absolute deviation from the correct angle was recorded. Pointing targets were always on the same floor and not visible from the participant's position. Participants were not allowed to leave the location where the tripod was set up. After pointing towards the target, the participant was asked to estimate the egocentric euclidian distance (in a straight line) towards the pointing target. The participant's answer was scored as a percentage of the actual target distance. Next, the difficulty of the last navigation and pointing task were assessed. The participant indicated the difficulty of both tasks on two continuous Likert scales with anchor points of "too easy" and "too difficult". Difficulty was measured as the percentage of the participant's mark on the Likert scale (i.e. 0-100). Lastly, an empty floor plan (only the outer walls of the current floor of the building) was provided in which the participant had to draw his current position where the tripod was set up and also the position of the pointing target. The floor plan was aligned with the participant's view and the location of two landmarks (main entrance and side entrance) was shown on the floor plan to give the participant a better sense of distance and location. For the purpose of analyzing the participant's answers, the floorplan was divided into a three by three array of sections as seen in the appendix. The different sized sections were chosen to match the irregular layout of the building. The deviation from the correct section was counted so that diagonal movement was not allowed. The highest possible error score for any response is therefore four, given that the participant's mark is in the opposite corner of the building from where the correct target location is.

2.4 Procedure

Participants were tested individually with each session lasting between two and three hours. The experiment started at the Psychology Building at the University of Canterbury, New Zealand. After an initial briefing and additional information about simulator sickness, participants gave written informed consent. During the first 15 minutes questionnaires for demographic background, computer experience and the SBSODS were completed. Next, the participant was taken to the Erskine Building. The experimenter led the participant along the predefined training route through the building and explained all twelve targets. After leaving the training environment, the participants returned to the Psychology Building where they completed the MRT, OPTT and CRT within about 30 minutes. Before navigation performance was tested, a list of the twelve targets in random order was presented. The participant had to recall as many details about the target locations as possible. Such information included context information (what happened near the object), floor number, side of the building, location of the reference point or how to get to the target. All answers were recorded, scored for their correctness (each item either as correctly or incorrectly remembered), and the participant received feedback and further explanations about all targets. If the participant felt confident about all target locations and no questions remained, the navigation assessment started. Half of the participants were guided towards a different side entrance of the Erskine building where the assessment began. The other half of the participants were tested at the HIT Lab New Zealand, where the VisionSpace back projection theater is set up. Initially, participants were asked to report any symptoms of simulator sickness using the SSQ and received an introduction to using the mouse for navigation through the VE. A simple open environment with two visible targets was used as a practice scenario for navigation and pointing tasks. After each participant was comfortable with using the mouse, the virtual assessment started at the exact same virtual side entrance which was also used for the real-world assessment. The remainder of the testing session was identical for both groups as has been described previously. The SSQ which participants had to fill out again after their exposure to the VE was the only additional questionnaire for this group. Before and after scores were compared and analyzed.

©2010 ICDVRAT; ISBN 978 07049 15022

2.5 Statistical Analysis

The basis of the present study is a comparison of real and virtual navigation with a prediction of equivalence being made between both groups. This by itself poses a problem, because most statistical procedures are designed to test for differences between groups. Further, the absence of a significant difference is not to be interpreted as both groups being equivalent (Nickerson, 2000). Any difference between two or more groups can potentially be shown to be statistically significant, given a large enough sample size. Thus, a different method for interpreting the equivalence of groups is needed. Tryon (2001) and Tryon and Lewis (2008) suggest the use of a range (delta) which is defined by the extreme points of adjusted inferential confidence intervals (ICIs) of both groups. If delta is smaller than a predefined range of indifference, statistical equivalence is established. However, the range of indifference needs to be determined on substantive grounds which is not a trivial task for any research question.

In conclusion, a hybrid approach to statistical analysis has been chosen. Firstly, both groups are compared with standard statistical tests (i.e. t-tests for independent means) seeking to find a significant difference. Effect sizes for all comparisons are also calculated following the procedures of Cohen (1987). Lastly, the ICIs for both groups are calculated and their overlap is determined. The overlap measure indicates the percentage of participants which are included in the overlapping area of both groups' ICIs.

3. RESULTS

Levene's tests for homogeneity of variances have been conducted for all comparisons of navigation performance and pen and paper tests. The variances for Total Time of Stops differ significantly between the VE and real building group ($F(1,27) = 14.889$, $p = 0.0006$). No other Levene's test shows a significant difference. Lilliefors' tests for normality indicate that none of the distributions reported in this study differ significantly from a normal distribution.

As predicted, most critical navigation parameters did not show a significant difference at $\alpha = 0.05$ (see table 1). Performance in the pen and paper tests was not significantly different between the real-world and VE group. There was no effect evident for the CRT ($d=0.19$). MRT and OPTT showed small effect sizes of $d=0.48$ and $d=0.41$ respectively.

For navigation distance no significant difference was observed. Participants in the VE group on average travelled 46 meters further than participants in the real environment. Cohen's d was found to be small for this comparison ($d=0.37$). Confirming our expectations, there was a significant difference between navigation time of both groups. Participants spent significantly more time navigating through the virtual Erskine Building which results in a large effect size ($d=1.76$). Variance for the VE group was especially large and individual performance ranged from 501s to 2111s. Navigation time was based on the total time for all six navigation tasks from the moment the participants started walking along the first path until they found the last navigation target. Pointing tasks were not included in this measure.

The number of cues that were given to the participants did not differ significantly between both groups. However, a medium effect size ($d=0.6$) indicates that there was a difference in the number of help cues the VE group and the real-building group received even though this difference did not reach significance. This might also be due to the large variance in the VE group where two participants received 20 and 21 cues respectively. When both participants are excluded from the analysis, the effect size is reduced to 0.24. A t-test for independent means shows no significant differences between both groups when the outliers are removed ($t(25)=-0.622$, $p=0.539$).

The comparison of navigation decisions is of central importance, as this measure directly quantifies how participants navigated through the real and virtual environment. As predicted, no significant differences were found for the number of optimal decisions and the decision error score. No effect was found for the number of optimal decisions ($d=0.17$) and a small effect was evident for the decision error score ($d=0.28$). Systematic errors when drawing navigation and pointing targets onto empty floor plans showed no significant difference. The effect size for this comparison was found to be small ($d=0.22$). No significant difference was found for distance estimations in both groups. Nonetheless, participants who were assessed in the VE appeared to consistently underestimate the true distances towards pointing targets ($d=0.66$). The largest estimation errors occurred when judging the shortest distance. For the distance between Elevator and Main Entrance (6.97 meters) average judgements were 156.9% and 172.96% of the true distance in real building and VE respectively. This was the only overestimated pointing target for the VE group across all tasks. A large effect size for angular pointing errors ($d=0.73$) indicates that pointing errors were larger in the VE than in the real building. The difference between both groups is non-significant. The remaining comparisons for number of

©2010 ICDVRAT; ISBN 978 07049 15022

stops and total time spent standing still both show large effect sizes (d=1.61 and d=1.67) and significant differences between both groups. Participants navigating through the VE stopped significantly more often and spent more time without virtual movement.

Table 1. *Means, Standard Deviations, P-Values, Effect Sizes and Confidence Interval overlap for all navigation measures.*

Measure	Mean±S.D. Real Group	Mean±S.D. VE Group	df	P-value	Effect Size d	CI overlap %
CRT	0.892±0.087	0.906±0.057	27	0.6037	0.19	23
MRT	0.822±0.065	0.851±0.059	26	0.2231	0.48	13
OPTT	38.156±23.832	30.224±14.796	27	0.2953	0.41	6
Navigation Distance	443.612±132.922	490.096±118.087	27	0.3296	0.37	24
Navigation Time	674.733±248.775	1380.5±520.627	27	0.0001*	1.76	0
Number of Cues	4.867±3.681	7.857±6.323	27	0.1281	0.6	3
Decisions Error Score	23.14±12.28	26.64±12.88	27	0.4684	0.28	21
Optimal Decisions	12.86±2.96	13.36±2.76	27	0.6477	0.17	29
Floor Plan Errors	6.73±3.37	7.57±4.29	27	0.5620	0.22	38
Distance Estimation	120.01±50.91	90.42±38.4	26	0.0944	0.66	3
Angular Pointing Errors	30.983±19.354	45.228±19.848	27	0.0608	0.73	0
Number of Stops	17.733±10.43	40.357±17.627	27	0.0002*	1.61	0
Total Time of Stops	171.4±111.617	589.746±388.33	27	0.0004*	1.67	0

Note: * indicates a significant difference at $p < 0.05$; CRT – Card Rotations Test; MRT – Mental Rotations Test; OPTT – Object Perspective Taking Test

In addition to the aforementioned analyses, inferential confidence intervals (ICIs) were calculated for both groups of all measures (Tryon, 2001; Tryon & Lewis, 2008). This was done to further investigate the equivalence of the two groups. By simply looking at the results of a standard t-test it is impossible to conclude that two groups are the same. The amount of overlap, that is the number of data points in the overlapping range of both ICIs, is an indication for the equivalance of both groups. However, as a result of this analysis almost no overlap was evident (see table 1). Floor plan errors showed the highest overlap with eleven of the 29 participants in the overlapping range of the two groups' ICIs (38%). All remaining participants were located to the extreme left and right of the distribution of error scores. As expected no overlap was found for variables which also showed a significant difference.

Correlations of pen and paper tests (MRT, CRT, OPTT) with our navigation parameters were non-significant throughout. Only CRT score and errors in the floor plan task correlated significantly ($r=-0.516$, $p=0.007$) such that higher CRT scores are associated with less errors in this task. Also, age and sex showed no significant relationship towards any of the navigation measures.

Computer experience of the participants in the VE group was correlated with all navigation outcome measures. Correlations were generally negative and non-significant. Computer experience and the number of optimal decisions along the traversed route are positively correlated ($r=0.564$, $p<0.05$) which suggests that participants with higher computer experience performed better in the VE.

The participant's experience with the VE was almost entirely positive. Those participants who were unaffected by simulator sickness enjoyed the test session very much. While few participants suffered from mild symptoms of simulator sickness and three participants had to withdraw from the study due to more severe symptoms, the average increase of the total score from pre-assessment to post-assessment was 32.21 (SD=40.37) over 18 participants. The three participants who withdrew from the study reported total scores of 134.6 (two of them) and 120. Five of the participants showed no change in their score or even lower symptoms compared to the initial SSQ assessment.

4. DISCUSSION

In this pilot trial, validity of performance measures in a complex virtual building was assessed and navigation performance in the VE and its real-world counterpart were directly compared. The navigation tasks focused on configurational knowledge of the building and the 29 participants were required to make inferences about the shortest routes which had not been part of their previously shown learning route.

Most navigation parameters did not show a significant difference between the real-building and VE group. When participants were required to make decisions along their travelled routes, their decision errors

©2010 ICDVRAT; ISBN 978 07049 15022

and their choices for the optimal, shortest route did not differ significantly between groups. Both variables are considered the most comprehensive indicators of navigation performance, because they capture most of the participants' behaviour. In addition to the standard statistical analyses, effect sizes were calculated in order to further support the hypotheses of equivalence of both groups. The small to very small effects for both variables supported the initial results. Another variable of importance is the number of cues which the participants received to find the navigation targets. Again, both groups did not differ significantly and a medium effect size was observed. Only after removing data of two participants who received most of the cues in the VE group, the effect was reduced to small size. Both participants had difficulties adjusting to the VE and using the navigational interface. Due to their difficulties to navigate adequately, abrupt viewpoint changes resulted in symptoms of simulator sickness so that breaks between navigation tasks were needed. Consequently, the removal of data points from this analysis seems justified.

A variety of other measures were used to quantify the participants' ability to find their way through the building and estimate the position of targets around them. None of these measures produced a significant difference, but effect sizes varied considerably between tasks. Distances in the VE were consistently underestimated which is in line with many previous findings in the literature (e.g. Witmer & Kline, 1998; Koh et al., 1999; Thompson et al., 2004). However, contrary to most experiments, targets were not visible from the participant's viewpoint and had to be judged based on configurational knowledge of the building rather than visual cues. An exception to the underestimations was apparent for the shortest true distance where participants in the VE on average overestimated distance by 73%. The participants' viewpoint for this task was mostly occluded by a virtual wall which differs to all other distance judgements where no occlusions were present. Thus, participants had to rely solely on their mental map of the building layout instead of using visual cues of the VE for their judgement. The resulting difference between both groups for this particular pointing task was very small and no effect was evident. This suggests that participants' beliefs about distances are naturally accurate or too long, but are contradicted by exposure to visual cues in the VE.

Angular pointing errors towards unseen targets differed substantially between groups which is shown by a medium effect. This difference is expected to be of technical nature. In the VE, participants carried out the pointing task by positioning a red dot in the desired direction. This red dot was rendered in the center of the three-screen display and was explained to be similar to an index finger for pointing in a direction. A tripod with a clock-hand was used in the real building which provided a top-down, exocentric way of pointing towards a direction. While the former method for pointing intuitively seems more accurate, the VE group made larger absolute errors for their bearing estimations. One possible reason for these errors is the distortion of the displayed VE. Displayed field of view and screen resolution did not match so that a distortion of the VE was visible on the side screens. This technical limitation needs to be addressed in future versions of navigation assessments to provide a better user experience and results of higher validity.

The number of stops and the total time participants stopped on their routes were intended to assess the extent to which each person showed orientation behavior. Participants in the real building used such stops to look around, search for landmarks and find their bearings. Unfortunately, many additional stops in the VE were due to difficulties with the user interface. Participants slowly adjusted to the navigation with a computer mouse and several additional stops were recorded when participants needed to shift the mouse to the middle of the table, because they were running out of space. Further, several users adopted a strategy of repeatedly pushing the left mouse button instead of holding it down for forward movement as intended. Many additional pseudo-stops were also recorded when participants walked up and down stairs. The collision detection with stairs was not as smooth as with other parts of the virtual model and needs refinement. Consequently, the computer-based analysis of stopping behavior was programmed to eliminate such "micro-stops" by setting a threshold of one second for the shortest possible stop. With these limitations in mind, it comes as no surprise that a significant difference for both variables of stopping behavior was observed and the results of these analyses cannot contribute to the interpretation of navigation ability as intended.

To further substantiate our hypotheses of equivalence for all navigation variables, an additional analysis was conducted which uses the amount of overlap of inferential confidence intervals (ICIs). General overlap between scores of both groups was very low for all variables. The analysis revealed that a substantial amount of data points were located at the extreme positive and negative ends of the parameters' distributions. The finding of such small overlap of our groups in light of no significant differences and small effect sizes suggests that further research needs to be conducted to explain navigation behavior in very complex natural environments.

During the course of this study it became apparent that several usability issues had to be addressed for the future use of VEs. In a series of preliminary usability tests, navigation interfaces were evaluated for their ease of use. Main criteria for using a three-button computer mouse were the widespread use of the device and little

©2010 ICDVRAT; ISBN 978 07049 15022

physical effort needed for handling the device. Both are especially important for single-handed use when the other hand is unavailable, for example in cases of hemiplegia. To address the issue of simulator sickness, further refinements need to be made to the projection of the VE. For future studies the separate rendering of three viewports, one on each of the three screens of the VisionSpace theater, solves the problem of perspective distortion. This solution was not viable for the present study as the virtual building was too large for three separate renderings. For clinical use of the application head-mounted displays and portable projectors are considered in future trials.

During testing sessions the accurate modeling of smaller details emerged as an important aspect of the VE. Several participants reported using posters on the corridor walls for orientation. Unfortunately, due to time-restraints most posters and several other non-permanent minor details had not been included in the virtual model of the Erskine building. These limitations can easily be addressed with a more efficient work flow which optimizes the integration of Google SketchUp and Unity in the development cycle of a VE. The integration of this workflow into clinical day-to-day routine at a rehabilitation hospital will be tested in upcoming trials.

In order to consider the use of VEs in cognitive rehabilitation the difficulty of three-dimensional environments has to be evaluated. Such quantification of difficulty is necessary to provide alternate versions of navigation tasks, to classify routes and environments which patients are exposed to, and to adjust training difficulty in the context of a comprehensive rehabilitation training. In recent experiments, researchers manipulated the number of turns or the length of the route, because they are simple to measure and implement in an experimental setting. However, most real-world environments cannot be compared to the average office corridor in a university building. Residential houses, shopping malls, train stations or many other places often have multiple floors and there is more than one viable path which leads to the target. For simulation of these scenarios different measures need to be found in order to assess and score complex behavior in a standardized, systematic way. Braaksma and Cook (1980) propose a line-of-sight approach for landmarks in complex buildings like transportation terminals. How visibility, number of possible routes, results of pathfinding algorithms or other yet undefined variables influence the navigation performance in complex environments must be subject to further investigation. In addition, the relationship of VE performance and well-established clinical measures of spatial abilities needs to be examined. The results of Nadolne and Stringer (2001) and Kozhevnikov and Hegarty (2001) suggest that small-scale tasks like mental rotation place different demands on the cognitive system than navigating through the environment. Hence, more ecologically valid assessments are needed and the continued evaluation of VEs for such purpose seems justified.

In conclusion, the VE assessment has proven to be a useful tool for accurately capturing a complex skill like navigation ability. Through the strengths of virtual reality environments the capture, interpretation and visualization of navigation data has been greatly improved. However, our results show no correlations with other measures of spatial ability and the complexity and high variability of our data did not allow for an unambiguous interpretation. This suggests that measuring navigation ability in all its facets is a highly complex matter which cannot easily be related to existing measures of configurational knowledge of environments. To further increase the validity of gathered navigation data, several improvements towards higher usability of the VE are necessary. Issues of simulator sickness, display distortion and model detail of the VE need to be addressed. With refined navigation measures and larger sample sizes more insights into the underlying factors of navigation performance variability are expected. Such insights are especially needed to utilize more ecologically valid assessments, because with higher ecological validity complexity of the assessment increases substantially.

5. REFERENCES

J Cohen (1987), Statistical power analysis for the behavioral sciences (rev. ed), Lawrence Erlbaum Associates, Hillsdale, N.J.

R B Ekstrom, J W French, H H Harman and D Dermen, *Kit of factor-referenced cognitive tests*, Educational Testing Service, Princeton, NJ, 1976.

H Goldberg (2004), Computer/Internet Experience Skills Questionnaire for: Internet Diabetes Trial at Harborview, Retrieved June 26, 2010, from *http://www.hetinitiative.org/grantee_instruments/UwashHart_Baseline%20Computer%20Skills%20Survey.pdf*.

M Hegarty, A E Richardson, D R Montello, K Lovelace and I Subbiah (2002), Development of a self-report measure of environmental spatial ability, *Intelligence*, **30**, pp. 425-447.

©2010 ICDVRAT; ISBN 978 07049 15022

M Hegarty and D Waller (2004), A dissociation between mental rotation and perspective-taking spatial abilities, *Intelligence*, **32**, pp. 175-191.

R S Kennedy, J M Drexler, K S Berbaum and M G Lilienthal (1993), Simulator Sickness Questionnaire: an enhanced method for quantifying simulator sickness, *International Journal of Aviation Psychology*, **3**, *3*, pp. 203-220.

M Kozhevnikov and M Hegarty (2001), A dissociation between object-manipulation spatial ability and spatial orientation ability, *Memory and Cognition*, **29**, pp. 745-756.

M J Nadolne and A Y Stringer (2001), Ecologic validity in neuropsychological assessment: Prediction of wayfinding, *Journal of the International Neuropsychological Society*, **7**, pp. 675-682.

R S Nickerson (2000), Null hypothesis significance testing: A review of an old and continuing controversy, *Psychological Methods*, **5**, *2*, pp. 241-301.

A E Richardson, D R Montello and M Hegarty (1997), Spatial knowledge acquisition from maps and from navigation in real and virtual environments, *Memory and Cognition*, **27**, *4*, pp. 741-750.

R A Ruddle, S J Payne and D M Jones (1997), Navigating buildings in "Desk-Top" virtual environments: Experimental investigations using extended navigational experience, *Journal of Experimental Psychology: Applied*, **3**, *2*, pp. 143-159.

P W Thorndyke and B Hayes-Roth (1982), Differences in spatial knowledge acquired from maps and navigation, *Cognitive Psychology*, **14**, pp. 560-589.

W W Tryon (2001), Evaluating statistical difference, equivalence, and indeterminacy using inferential confidence intervals: An integrated alternative method of conducting null hypothesis statistical tests, *Psychological Methods*, **6**, *4*, pp. 371-386.

W W Tryon and C Lewis (2008), An inferential confidence interval method of establishing equivalence that corrects Tryon's (2001) reduction factor, *Psychological Methods*, **13**, *3*, pp. 272-277.

S G Vandenberg and A R Kuse (1978), Mental rotations, a group test of three-dimensional spatial visualization, *Perceptual and Motor Skills*, **47**, pp. 599-604.

B G Witmer, J H Bailey and B W Knerr (1996), Virtual spaces and real world places: transfer of route knowledge, *Int. J Human-Computer Studies*, **45**, pp. 413-428.

©2010 ICDVRAT; ISBN 978 07049 15022

APPENDIX

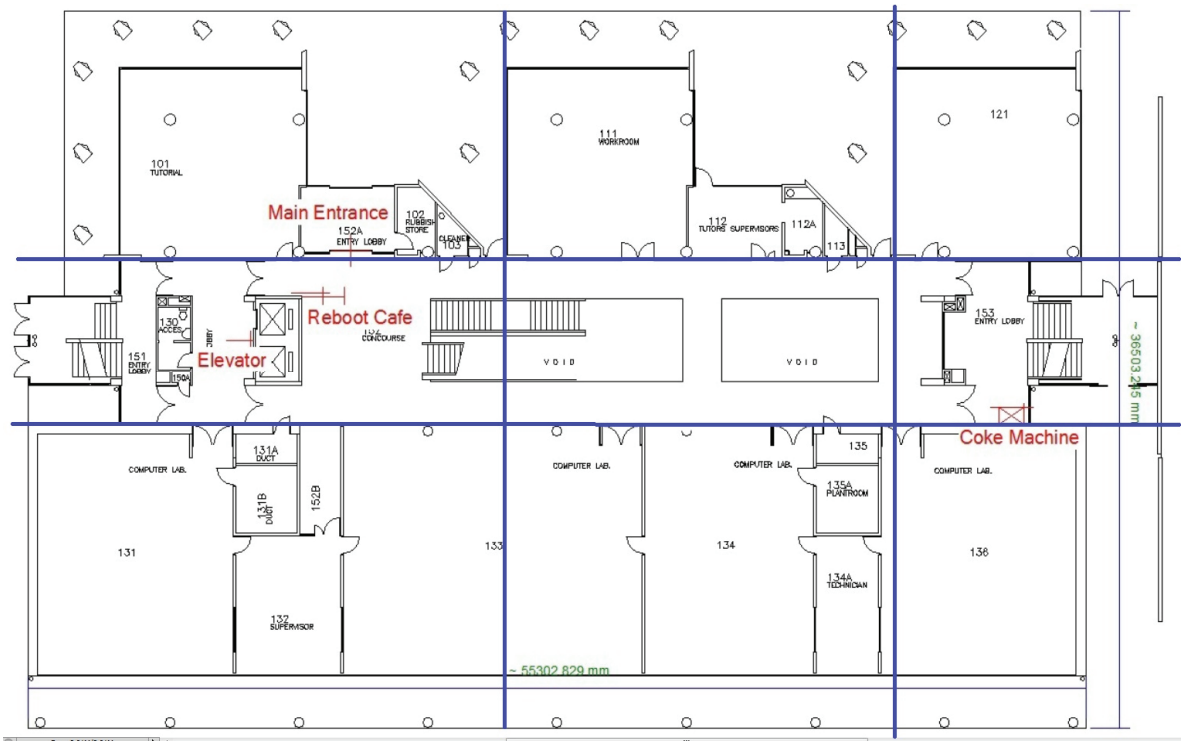


Figure 1. *Floorplan of Erskine Building (first floor), all four targets are marked, scoring grid for floor plan task in bold lines across building.*

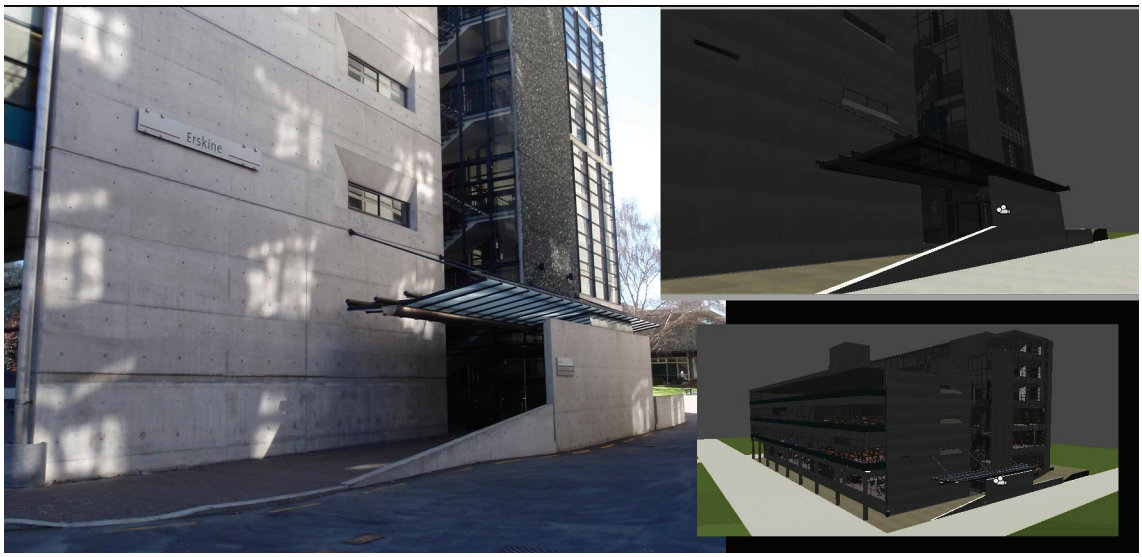


Figure 2. *Erskine Building (side entrance), real building and virtual counterpart rendered in Unity Game.*

Figure 3. *Experimental set up at the VisionSpace theatre, HIT Lab New Zealand.*

Wearable device to assist independent living

R J McCrindle[1], V M Williams[2], C R Victor[3], A P Harvey[4], S R Nyman[5],
J Barrett[6], H Hogarth[7], P Levene[8], R Smith[9], P Panek[10],
G Edelmayer[11], P Mayer[12], P Needham[13], N Floratos[14]

[1,4,6,7]School of Systems Engineering, University of Reading, Whiteknights, Reading, Berkshire, UK

[2,3]School of Health Sciences and Social Care, Brunel University, Kingston Lane, Uxbridge, Middlesex, UK

[5]School of Design, Engineering and Computing, Bournemouth University,
Talbot Campus, Poole, Dorset, UK

[8,9]Docobo Limited, 21 High Street, Bookham, Surrey, UK

[10,11,12]Fortec, Technical University of Vienna, A-1040 Favoritenstrasse, Vienna, AUSTRIA

[13]Cardionetics Limited, Grenville Place, Bracknell, Berkshire, UK

[14]e-ISOTIS, 40 Klitaimnistras, Athens, GR

[1]*r.j.mccrindle@rdg.ac.uk*, [2]*veronika.williams@brunel.ac.uk*, [3]*christina.victor@brunel.ac.uk;*
[4]*a.p.harvey@rdg.ac.uk*, [5]*snyman@bournemouth.ac.uk*, [6]*j.barrett@rdg.ac.uk*,
[7]*harriethogarth_32@hotmail.com*, [8]*peter.levene@docobo.co.uk*, [9]*robert.smith@docobo.co.uk;*
[10,11,12]*enable-fortec@fortec.tuwien.ac.at*, [13]*pneedham@cardionetics.com*, [14]*nick@e-isotis.org*

[1,4,6,7]*www.reading.ac.uk/sse*, [2,3]*www.brunel.ac.uk*, [5]*www.bournemouth.co.uk*, [8,9]*www.docobo.co.uk*,
[10,11,12]*www.is.tuwien.ac.at*, [13]*www.cardionetics.com*, [14]*www.e-isotis.org*

ABSTRACT

Older people increasingly want to remain living independently in their own homes. The aim of the ENABLE project is to develop a wearable device that can be used both within and outside of the home to support older people in their daily lives and which can monitor their health status, detect potential problems, provide activity reminders and offer communication and alarm services. In order to determine the specifications and functionality required for development of the device, user surveys and focus groups were undertaken and use case analysis and scenario modeling carried out. The project has resulted in the development of a wrist worn device and mobile phone combination that can support and assist older and vulnerable wearers with a range of activities and services both inside their homes and as they move around their local environment. The device is currently undergoing pilot trials in five European countries. The aim of this paper is to describe the ENABLE device, its features and services, and the infrastructure within which it operates.

1. INTRODUCTION – AN AGEING SOCIETY

Ageing is one of the greatest social, economic and health challenges of the 21st century. Europe is the continent with the highest percentage of people aged over 65 years (17% of the overall population), predicted to rise to 29% by 2050 (Eurostat, 2004; Börsch-Supan *et al*, 2005). The ageing phenomenon is due to a decrease in fertility coupled with increased longevity (Peace *et al*, 2007). There is an accompanying increase in the 'oldest old'. Approximately three per cent of the EU population is currently aged 80 years or over, and the number is projected to virtually triple in the next 50 years (Peace *et al*, 2007). Life expectancy for women in the EU is currently 81.2 years and 75.1 years for men (Peace *et al*, 2007); women account for 60% of the population aged 65 years and over.

Longer lives however do not necessarily translate into healthier lives. Women's longevity makes them more likely to suffer from the chronic diseases commonly associated with old age such as osteoporosis, diabetes, hypertension, incontinence and arthritis (Fried *et al*, 1999). Men are more likely to experience heart disease, pulmonary disease and stroke (Murtagh & Hubert, 2004). Inequalities in life expectancy and overall health status are found in European countries. Specific groups of older people are also at greater risk of ill-health than others. They include older women, members of ethnic and cultural minorities, those who are

©2010 ICDVRAT; ISBN 978 07049 15022

socially isolated and disabled older people (WHO, 2002). Improvements in standards of living, innovations in medical care and the availability of health care over the past 50 years have led to a greater number of older people living with physical or cognitive impairment as a result of chronic illness and/or the ageing process in the extended lifespan (Mukaetova-Ladinska, 2006).

Despite the difficulties caused by chronic ill health, many older people choose to remain living at home with appropriate equipment, care and support for as long as possible (DH, 2001, 2005). Assistive technology (AT) is one important means of helping people with age-related and other forms of disability to live their lives as independently as possible in their own homes. Assistive technology covers a vast spectrum of aids and devices, from basic shower adaptations to complex computerized medical devices that support the older person in managing their disability or long-term health condition.

The aim of this paper is to describe the ENABLE assistive technology device and the features, services and infrastructure within which it operates. Development of the device has been highly user-centred and hence this paper also reports some of the perceptions, requirements and issues that older people had in relation to development of such a device.

2. ENABLE – AIMS AND OBJECTIVES

The aim of the project has been to develop a personal, user-centred system, with services, for use by an elderly person in or out of the home, to mitigate the effects of any disability and to increase quality of life: independence, autonomy, mobility, communications, care and safety. The system is based on a distributed open platform, enabling other services to be added by third parties, by "plugging" into defined interfaces. The platform includes a mobile phone, enabling the user to get out and about, for visiting, shopping, recreation, etc, whilst maintaining contact for help and services.

The system is built round a dual platform of mobile phone and wrist unit, to which are added modular capabilities for (1) alarm functions, (2) control of appliances/other devices around the home, (3) identification of the user's location, and (4) health monitoring. The project addresses mobile phone accessibility by providing an accessible user interface extension, using the wrist unit and speech guidance.

The intended benefits of the system are to:

- Improve the quality of life for an elderly person wanting to lead, or continue to lead, an independent life
- Assist in carrying out daily activities
- Monitor health and activity, especially reduce the risk of having a fall or other trauma
- Improve access in emergency, for safely and security, especially in the case of a fall
- Facilitate social contacts
- Increase the length of time that the elderly person can stay at home before moving to an institution
- Improve the quality of life and costs for their carers, especially for friends or relatives that might not be living, or want to live, in the same house, but are anxious about leaving the elderly person by themselves
- Improve the standard of care provided by local social services, and the cost of providing that care
- Reduce the amount of time that the elderly person spends in hospital before they can be safely sent home
- Improve the quality of life for the elderly person recovering from treatment, or with a terminal illness, who wants to stay at home.

3. OTHER SYSTEMS FOR ASSISTED LIVING

There are a range of systems and devices already on the market or being developed in other projects which are positioned in competing or complementary market places for the ENABLE device and which provide useful information for comparing ENABLE's approach and intended performance with that of other RTD (Research and Technology Development) projects. These products include for example the Vivago alarm watch based on measurement of physiological sensors (Vivago, 2010); the Equivatal life monitoring system (Equivital, 2010); the Tunstall's RTX telehealth home monitor (Tunstall 2010); and Movea's Motion Pod (Movea, 2010). Projects investigating assistive technology for independent living include: the i2home project (i2home, 2010); the CAALYX Complete Ambient Assisted Living Experiment (CAAlYX, 2008), Emerge

©2010 ICDVRAT; ISBN 978 07049 15022

(Emerge, 2010) and Soprano (Soprano, 2010) to name but a few; other projects examples may be accessed via the Foundation for Assistive Technology (FAST, 2010).

4. USER REQUIREMENTS AND CONCERNS

Design and development of the ENABLE device has been highly user-centric with older people being involved at all stages of the system lifecycle. Two such activities that influenced design of the device were the user surveys and focus groups conducted in order to explore user needs and concerns. The key findings from these are summarised in this section.

4.1 User Surveys Approach

In an initial user survey to gain a broad understanding of user needs, questionnaire data were collected from 96 older people in six European countries: UK (age rage 59-91, mean age 74.5 years), Greece (age range 68-80 years, mean age 73 years), Austria (age range 63-94 years, mean age 72 years), Czech Republic (age range 75-94 years, mean age 83 years), Belgium (age range 57-92 years, mean age 78 years) and Spain.

The sample included older people from volunteer groups and residential care with some degree of ill-health or functional difficulties. Participants were accessed via workshop days, residential and nursing homes and volunteers in six European countries. The majority (over 80 %) of participants were retired with less than 5% working full time and less than 10% working on a part time basis. We did not collect any specific data on education background as the educational systems between countries vary widely. However, the vast majority of participants (over 90%) completed secondary education, with some people being educated to degree level.

Participants' knowledge and current use of technology ranged from everyday use of communication technology devices (such as computers, internet, mobile phones) and household electrical appliances to very little or no use or previous knowledge of communication technology devices.

Questionnaires were translated into the different languages (Greek, German, Czech, Dutch and Spanish) and were predominately self- administered, although some were administered by an interviewer where the participants requested help with filling out the questionnaire.

The initial questionnaire consisted of questions relating to socio-demographic background, health status and functional difficulties, and explored areas of ownership of home entertainment and communication devices, difficulties in using such devices, safety and security, home adaptations, concerns of using ENABLE device, and importance of features of ENABLE device. A second survey with a further 98 respondents was conducted across UK, Belgium, Czech Republic and Greece in order to explore in more details the wrist unit concepts. Data were entered into SPSS and Excel and descriptive statistics were used to analyse data.

4.2 Focus Group Approach

A total of 47 participants took part in nine focus groups in the UK. The majority of participants were female and between 70 and 80 years of age. Most participants were retired. The focus groups included healthy older volunteers, older people with chronic conditions and disabilities (such as Parkinson's disease, stroke, vision impairment, respiratory and cardiac conditions) as well as some carers. The aim of these focus groups was to explore in depth end user needs and identify any issues of concern in relation to users being shown early prototype (PPT1) devices/mock-ups (Figures 1-3 and 4-5). Prior to commencing focus groups, written consent was taken from all participants. A prepared interview schedule was used to ask participants about the difficulties they faced on a daily basis. Participants were then introduced to three different space models and/ or pictures of mock up devices. The researcher explained the device and its potential functions and participants were then asked for their views on the design, functionality and potential concern regarding the use of such a device. A second researcher would take notes during the focus group on group dynamics and any issues that were identified as important. The interview schedule was amended after each focus group after taking into account responses from participants. This allowed the research team to explore specific issues raised in more detail with subsequent focus groups. Focus groups were tape-recorded, transcribed, imported into Atlas.Ti (a software package for qualitative data) and analysed using thematic analysis.

4.3 Overall Design

The main issues arising from the user perspective with regard to overall design stemming from the questionnaires, focus groups and individual sessions with users trialling PPT1 are summarised below:

4.3.1 Wearing the device. Participants (across all participating EU countries) seem to prefer wearing a device on the wrist. This finding is supported by both survey data with over 100 participants across five EU countries (over 55% of participants preferring to wear the device on the wrist) and focus group data from the

©2010 ICDVRAT; ISBN 978 07049 15022

UK. This therefore led to the recommendation that the device to be developed within ENABLE should be a wrist worn device as this seems most acceptable to end users across selected EU member states, to both men and women and all age ranges. Although some concern was expressed by the participants with regard to wearing the device at all times (such as discomfort and for practical reasons), respondents also saw this as a benefit as it would eliminate the risk of forgetting to take the device with them which could be problematic in case of an emergency.

Figure1. *PPT1 Concept A*

Figure 2. *PPT1 Concept B*

Figure 3. *PPT1 Concept C*

4.3.2 Overall concept issues. Concepts A/B were the preferred versions of the WU, i.e. end users preferred the square screen with buttons on the side as opposed to buttons on the bottom of the screen. This may relate to ease of using buttons with one hand, as end users will be able to use the device much like a clock design with buttons on the side (and use their thumb for stabilising the hand that uses the buttons) whereas buttons on the bottom of the screen require a more stable hand. In addition, concept C also displays buttons with small spacing and would therefore be difficult to use for people with dexterity problems.

The main issue raised by end users in relation to the overall design was weight. Women in particular were concerned about comfort regarding the weight of the device. This issue was also of great concern to those end users who suffer from conditions that affect muscle strength in the wrist/ hand, such as arthritis, stroke and Parkinson's disease and frailty associated with old age.

Although the overall size and aesthetics of the WU was of some concern to end users, by which they preferred a slim version that would not appear too bulky, focus group data clearly indicates that functionality and ease of use of the WU would override any aesthetics concerns. This suggests that within reason end users may be willing to accept a larger size WU if this would lead to a device that was more user friendly (in terms of button size/ spacing; text size and simplicity of functions).

4.3.3 Interface and access to services. Several areas of end user needs with regard to the interface and access to services were identified:

Screen face: With regard to the clock screen options, respondents showed a clear preference for the digital clock screen over the analogue clock. However, some variance between EU countries has to be noted. Respondents from continental EU states did not like the am/pm display but would prefer the 24 hour clock display. Although the majority of respondents preferred the digital clock screen, a large number of respondents noted that they would like an analogue screen but with numbers on the clock face.

Colour scheme: End users showed a clear preference for a simple colour scheme with high contrast colours, such as black text/icons on a white background. However, such a colour scheme has high power consumption and therefore we suggested a dark/light colour scheme, such as gold on black to optimise power usage whilst providing high contrast. Busy backgrounds containing multiple colours or patterns were disliked by the vast majority of respondents across all countries.

Screen icons and text size: The vast majority of respondents preferred simple screen icons with text displayed with minimal extras, i.e. arrows, additional 'back' and 'select' buttons were disliked. Icons should be displayed on a uniform background preferably in a contrasting colour to text and icons (such as dark colour on light background). *The font size* was found to be acceptable by most respondents, however, bigger spacing between words would be preferable and some participants from Greece preferred capital letters.

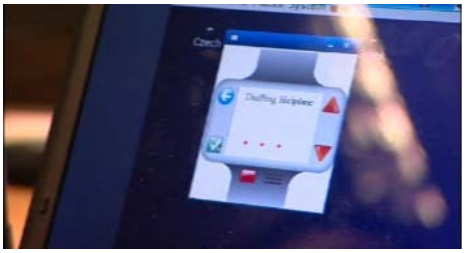
4.4 Views on Specific Functions

The following functions were identified as most important to older people across all countries involved.

4.4.1 Emergency function. The emergency function was seen as one of the most important functions of the device. Participants wanted a standard alarm system as well as inclusion of information of location in emergency and (to a lesser degree of importance) the possibility of pictures in an emergency. Participants liked both, activation by pressing button or voice activation, to trigger the alarm system.

©2010 ICDVRAT; ISBN 978 07049 15022

4.4.2 Falls detector/prevention. These functions were mainly discussed in relation to the emergency function and respondents were mainly concerned with the range of the device (i.e. will it work outside) and risk of failure (i.e. if the person has fallen onto the arm on which the WU is worn how can the alarm be activated if the button cannot be reached). These concerns seem to be related to current fall alarms and as such indicate that these are not adequate in addressing the needs of older people who are at risk of falling. These aspects need to be considered during the development of PPT2 in order to ensure the falls functions address end user concerns. For example, the device should incorporate an alarm that would automatically be triggered when the person has fallen rather than the person having to activate the alarm manually once fallen.



Figures 4 and 5. *Syd taking part in PPT1 trials giving feedback on initial designs and mock-ups*

4.4.3 Medical device. The use of the wrist worn device as a medical device related mainly to two aspects: the reminder function for medication and the health status monitoring.

Reminder function (medication): The majority of participants prefered an audio or vibrating alarm to a visual alarm as a reminder function. This aspect of the device is also of benefit to carers as it will alleviate them of some of their responsibility to remind the older person to take their medication. The reminder function was also seen as very useful for those conditions where it is important to take medication at a certain time every day (e.g. Parkinson's disease, diabetes, Alzheimer's disease).

Health status monitoring: Health status monitoring such as blood pressure, pulse, temperature monitoring was seen as an important function of the device with over 50% rating this function as important or very important. It was perceived to serve as a way of keeping someone else (e.g. in response centre) aware of health status and deterioration, however it could also be used to facilitate diagnosis of chronic health problems.

Health status monitoring is of particular interest as a large proportion of older people are living with a chronic health condition (this was reflected in participants, with over 65% indicating they were living with a long term condition). In addition to basic vital signs monitoring (blood pressure, pulse, temperature, ECG) it would be useful to include a way for gathering medical information which would allow care providers to manage these older people better in their own homes. This could be achieved by using standard sets of questions which would be collated and monitored over time in order to detect any abnormalities.

Participants showed very little concern (only 7.5% indicate great concern) about sending medical data to health care professionals or health care assistants (26% indicate great concern) however showed much greater concerns about sharing data with non medical staff (38% indicate great concern). This result may effect the way medical data is handled in the response centre and staff employed.

4.4.4 Text function. The ability to text messages from the device was less important compared to other functions but was of interest to a sub group of participants (e.g. those with speech impairment). Concerns were raised related to the use of buttons, so the WU needs to include buttons of a reasonable size, spacing and most preferred textured surfaces.

4.4.5 Speech/Automatic Speech Recognition (ASR). The majority of respondents (over 60%) would like a speech function/ASR included in the device, in particular those end users with vision deficits. However some concerns were raised regarding volume of speech (output) and whether the device will 'understand' speech input for those end users who have speech impairments (e.g. Parkinson's Disease/ Stroke). In addition, survey data showed that a majority of the participants were not willing to wear headphones or earpieces and therefore the volume of speech output needs to be at a level that is loud enough to be understood even by those end users who have hearing difficulties.

4.4.6 Environmental control. The environmental control function seems to be more important to carers than the older person as it appears to provide reassurance to carers when the older person is left alone. Carers indicated that they are often worried whether the older person left appliances on (such as cooker, gas hob,

©2010 ICDVRAT; ISBN 978 07049 15022

etc.) which would place the older person at risk. An environmental control function would alleviate such concerns, as all appliances could be switched off using the device.

4.4.7 GPS. The GPS function was also particularly important to those carers who looked after older people with dementia as it would offer reassurance of the location of the older person should he or she get disorientated or wanders off and get lost. End users themselves would also like further information included in the GPS function, such as local maps, traffic information and directions (much like a satellite navigation system).

4.5 Concerns to be Addressed

Participants also expressed concerns about using a wrist worn device. These primarily related to complexity of functions, privacy, built quality, safety concerns and ease of use of the device.

4.5.1 Complexity of design. One of the key concerns raised by participants with regard to using a wrist worn device was the potential complexity of functions. Participants preferred simplicity of menus and access to functions and a limited number of functions with the focus on those functions that are most needed. As such, end users appear to prefer a device that is individually tailored to them in terms of functions included as this approach would reduce the risk of complicated menus with numerous functions that may not be needed by an individual.

We would therefore recommend that the wrist unit is developed to be as 'individualised' as possible, which could be achieved by developing more than one prototype/system, e.g. by having one model for older people living with long-term conditions, one model for those needing some support in the home environment (activity monitoring) and one for those at risk of falls and with memory deficits, such as dementia.

4.5.2 Concerns about privacy. Another concern raised by participants related to privacy and confidentiality. Participants also showed much greater concern in sharing medical data with non-medical staff (e.g. administrators) than with medical or health care trained staff. This will therefore affect the staffing in the response centres and may require staff to be trained in some aspects of health care as well as issues relating to confidentiality and data protection.

4.5.3 Build quality and safety concerns. Some concerns were raised about build quality of the device, for example whether the WU will be water proof and shock proof, as end users were concerned about wearing the device in the bath/ shower and knocking the device on furniture or when having a fall. In addition, participants were also worried about getting entangled in clothes/catching the device on furniture such as curtains, in case of large buttons protruding from the device.

4.5.4 Ease of use. The ease of use of the device in terms of hardware features was another key concern of participants. Issues raised by participants related to the size and spacing of buttons as well as the texture of buttons. Buttons need to be spaced adequately (which may explain the preference of space model option A and B over option C as the former two designs have buttons on the side rather than on the face of the unit) as well as large enough in size for those users with dexterity problems to use the device. Participants would also prefer to have textured surfaces on buttons as this would facilitate using the device, particularly for those people with dexterity problems.

4.6 Opportunities for Carers

The use of a wrist worn device such as ENABLE could also have benefits for (informal) carers of older people. The main benefits for carers (as perceived by themselves) include increased independence and reassurance thus potentially increasing carers' quality of life. Carers clearly indicated that the use of a wrist worn device by the older person they cared for, would give them more independence as they would be able to leave the older person on their own for periods of time as well as use the device to help manage tasks such as medication reminders on a daily basis.

Carers often feel overburdened and have little time for themselves. Therefore a device such as ENABLE would increase their independence, and allow carers to have more time for themselves and thus potentially increase their quality of life as well as that of the older person. Another perceived benefit of the wrist worn device to carers was reassurance that the older person was well and safe, or in an emergency would be able to contact the carer or the response centre as appropriate. This would allow carers to respond more quickly to the older person's needs.

©2010 ICDVRAT; ISBN 978 07049 15022

5. ENABLE PLATFORM

ENABLE as a delivery solution consists of a number of key components (see Figure 6) as outlined below:

- The Service Centre software including the business layer components, the database schema and the web based user interface layer.
- The ENABLE application software for the Mobile Phone.
- The electronic and mechanical hardware for the Wrist Unit.
- The software for the Wrist Unit, consisting of the specific configuration of the operating system and the application software for the main processor and the firmware for a low-power micro-controller associated with sensors.

Following the user requirements, the ENABLE device was developed to meet the following requirements and service provision:

- Open system design to allow tailoring for an individual's/market needs and which allows integration of new sensors, and data collection and services to be remotely deployed and configured across the web.
- A device that can be used both inside and outside of the home and in which a number of previously separate features (falls detection, environmental control, GPS etc.) have been integrated into one unit.
- Simple, flexible and practical user interface which has a colour user interface, language and user independent voice commands and a simple five button operation (Figures 7 and 8).
- Wrist worn falls detection including differentiation between hard and soft falls, and falls prevention.
- Integrated social and healthcare functionality for monitoring of long term conditions and medication reminders.
- Auto connection to mobile/communications for quick and simple dial from the wrist unit.
- Context control of the user's environment e.g. for switching on/off lights as the user enters/leaves a room and location awareness of the use as they move between rooms.
- Emergency call and prompting and inside and outside location detection.

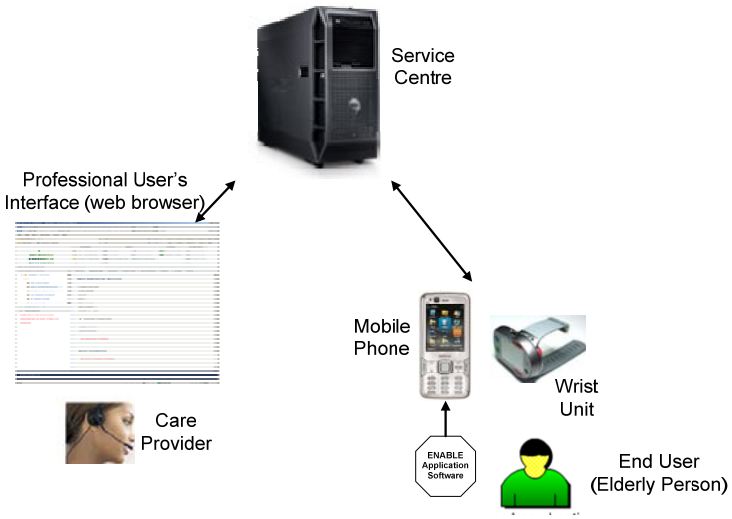


Figure 6: Overview of ENABLE Platform Prototype.

It has also been developed with accessibility in mind:

- Navigation of the user interface can be performed using speech commands as an alternative to buttons. These commands are language independent such that any user voice can operate them.
- The buttons and the visual display are large, compared to those on a watch, giving improved access for elderly people for time functions. Such accessibility advances the state of art for accessibility of mobile technology and telehealth and telecare services, especially for elderly people.
- The system is designed to be easily used by somebody with a visual impairment, as they don't have to be able to see the screen. The buttons are in distinctive positions. The automatic speech recognition option gives added accessibility.

- Speech input gives accessibility for people with reduced vision and/or manual dexterity. Combined with single switch input, the system becomes accessible for people with little upper limb movement, tetraplegics, amputees, etc.

Figure 7. *ENABLE Interface/Strap System*

Figure 8. *ENABLE Command Buttons*

6. USER FOCUS, TESTING AND RESULTS

User trials of the ENABLE Wrist Unit device and the services it offers are being conducted in individual's homes and in care homes in the UK, Belgium, Austria, Greece and the Czech Republic between April and September 2010. Fifty wrist units have been manufactured for the trials and a series of short (two weeks) and long term (ten week) trials are taking place across the three month period in order to assess the success of the device, its aesthetics and usability of the interface, and the integrated functionality that it offers (Figures 9-12).

Figures 9 and 10. *ELSA, a resident at Vzw Cassiers Wzc in Belgium being trained to use the system*

Figure 11 and 12. *Vi, a UK participant using the system outside of and within the home*

7. CONCLUSIONS

ENABLE has sought to address a number of technical, integration and service aligned issues that if solved will provide a capacity for change currently not available through other programmes/devices. Elderly and vulnerable people are faced with a number of issues as they seek to maintain their independence and to maintain their quality of life. ENABLE for example:

- Has created an integrated technology platform capable of serving telecare, telehealth and the combined disciplines. The main innovation of ENABLE is the integration of formerly disparate

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

functionality (ECS, falls detection, telephony, care management, quality of life assessment etc.), into one mobile platform.

- Provides the capacity for different configuration profiles so that functionality is adapted to the special situation of the user. This approach also ensures that the ENABLE solution is open to facilitate changes and extension of performance and adaptation to future needs of an individual.
- Has a falls algorithm built into the ENABLE wrist unit that will differentiate between different motion profiles to allow a greater reliability for the detection of falls whilst removing false positives. The falls application can be integrated with applications so that a single device can be used for a range of services.
- Assesses users on a regular basis through a preventative question set using a standard tool that examines the issues of daily living that increase the risk of falling. This could be linked to a prompting service that suggest that the user sits down or stops what they are doing for a time thus removing or diminishing the risk of falling.
- Has created a wearable system capable of use at anytime and anywhere with a full range of services and support options including location and alert systems. This means that the device can be used both within and outside of the home.

Acknowledgements: The ENABLE Project (2007-2010) is funded in part by the European Commission in the 6th Framework Programme (project number: 045 563). Partners are: AT: fortec - Vienna University of Technology – IS, KII - Kompetenznetzwerk Informationstechnologie zur Förderung der Integration von Menschen mit Behinderungen; ES: ARTEC; UK: Docobo Ltd, Cardionetics Ltd., Reading University; CZ: Zivot 90; SP: Code Factory Ltd.; GR: E-Isotis, BE: Vzw Cassiers Wzc; Website http://www.enable-project.eu/. We would also like to thank all our user participants and especially Vi and Syd from the Reading user participant group and Elsa who is a resident at Vzw Cassiers Wzc in Belgium, who appear in our photos.

8. REFERENCES

A Borsch-Supan and H Jurges (eds) (2005), Health, Ageing and Retirement in Europe, *First Results from the Survey of Health, Ageing and Retirement in Europe* (SHARE), Mannheim: Mannheim Research Institute for the Economics of Ageing, Germany.

CAALYX (2008), Complete Ambient Assisted Living Experiment, http://www.caalyx.eu/ (accessed July 2010)

Department of Health (2001), *National Service Framework for Older People*, London: Department of Health.

Emerge (2010), Emergency Monitoring and prevention, http://www.emerge-project.eu/ (accessed July 2010)

Equivital (2010), Equvital Life Monitoring Systems, http://www.equivital.co.uk/Equivital%20Systems/ (accessed July 2010)

Eurostat (2004) , The Statistical Guide to Europe, In *Eurostat Year Book 2004*, epp.eurostat.ec.europa.eu/ cache/ITY_OFFPUB/KS-CD-04-001-2/EN/KS-CD-04-001-2-EN.PDF (accessed July 2010).

FAST (2010), Foundation for Assistive Technology, http://www.fastuk.org/home.php (accessed July 2010)

L P Fried, K Bandeen-Roche, J D Kasper and J M Guralnik (1999), Association of comorbidity with disability in older women: the Women's Health and Ageing Study: *Journal of Clinical Epidemiology* vol. 52, no. 21, pp. 27-37.

I2home (2010), Intuitive Interaction for Everyone with Home Appliances based on Industry Standards, http://www.i2home.org/ (accessed July 2010).

Movea (2010), Motion Pod Technology, http://www.movea.com/index.php/products/motionic-hardware/motionpod (Accessed July 2010).

E Mukaetova-Ladinska (2006) Towards living long and being healthy – the challenge for liaison psychiatric services for older adults, *Age and Ageing*, vol. 35, pp. 103-5.

K N Murtagh and H B Hubert (2004), Gender differences in physical disability among an elderly cohort, *American Journal of Public Health*, vol. 94, no. 8, pp. 1406-11.

S Peace, F Dittmann-Kohli, G Westerhof and J Bond (2007). The ageing world, In: J Bond, S Pearce, K Dittmn, F Kohli and G Westerhoff (Eds) *Ageing in Society* (3rd Edition). London: Age/British Society of Gerontology.

Soprano (2010), Service Oriented Programmable Smart Environments for Older Europeans, http://www.soprano-ip.org/ (accessed July 2010).

Tunstall (2010), Tunstall telehealth solutions, http://www.tunstallhealthcare.com/Default.aspx?ID=2197 (accessed July 2010)

Vivago (2010), Vivago telecare technology, www.vivago.fi (accessed July 2010)

WHO (2002) *Active Ageing – A Policy Framework*, Geneva: World Health Organisation.

©2010 ICDVRAT; ISBN 978 07049 15022

Designing a workplace for workers with motion disability with computer simulation and virtual reality techniques

P Budziszewski, A Grabowski, T Tokarski, M Dźwiarek,
B Kurkus-Rozowska, J Jankowski

Central Institute for Labour Protection – National Research Institute
Czerniakowska 16, Warsaw, POLAND

pabud@ciop.pl

www.ciop.pl

ABSTRACT

This paper describes preliminary results of a project aimed at adapting workplaces for workers with motion disability with computer simulation and virtual reality techniques. For this task, special software called the Troll and a computer human model with a visualization of maximal arm reach and preferred working space were developed. The Troll can be used to create a virtual working space, to adjust the human model's measurements and constraints to reflect a disabled person, and to analyze necessary modifications. The Troll also makes it possible to conduct research in an immersive virtual reality environment to assess a modified workplace and, if necessary, add further modifications.

1. INTRODUCTION

Employment of disabled people is a very serious social problem in Poland. According to data obtained from the Economic Activity Survey (conducted by Poland's Central Statistical Office), in 2009 nearly 2.1 million people with disabilities were of working age. Of these, only ~508 000 people are occupationally active, and ~443 000 actually worked. Persons with disabilities constitute nearly 10% of the working age population, but their share in total employment is lower than 4% (Chłoń-Domińczak and Poznańska, 2007). Such a low share of employed persons with disabilities may be caused by greater than average difficulties in finding a job, or less willingness or capacity to enter the labour market. The odds of finding work by occupationally active disabled people are about 20–40% lower than those of healthy people (Chłoń-Domińczak and Poznańska, 2007). Therefore, the crucial issue is to facilitate employment of people with disabilities to the extent to which they retain their ability to work and can use their skills and capabilities. One of the important aspects of this issue is adaptation of working environments for disabled people.

At the same time, computer simulation and virtual reality have become in recent years powerful tools that can be used in research on ergonomics and safety in the workplace (e.g., Foster and Burton, 2003; Mujber et al, 2004; Nivolianitou, 2006). In the USA, advanced research in this area is, for example carried out by the National Institute for Occupational Safety and Health (Department of Health and Human Services, Centers of Disease Control and Prevention). They study the use of virtual modelling for analyzing and assessing ergonomics and risk at workplaces in mines (Ambrose et al, 2005). Also in Japan, research on applying virtual simulation in analyzing accidents in the mining industry was conducted (Fukaya et al, 2003). Further examples of the application of virtual reality are research in the field of ergonomics of mining machinery operators (Foster and Burton, 2003) and identification of hazards and simulation of accidents, undertaken in order to improve the efficiency of decision-making (Duffy et al, 2004). In 2005 the European Union FP6 project VIRTHUALIS (Virtual Reality and Human Factors Applications for Improving Safety) was undertaken. As part of this project research is done to develop a method of using virtual modelling to consider the human factor when designing industrial installations, mainly in the chemical and petrochemical industries.

Research on the use of computer simulation and virtual reality in simulation of working conditions, accidents at work and ergonomic analysis is also performed in Poland, e.g. in the Institute of Mining Technology KOMAG (Winkler et al, 2006) and in the Central Institute for Labour Protection – National Research Institute (Budziszewski et al, 2010; Milanowicz and Budziszewski, 2010).

©2010 ICDVRAT; ISBN 978 07049 15022

Computer simulation and virtual reality tools can be also used to adjust a workplace to the needs of a person with a disability at the design stage and to study adjusting existing working environments. A strictly virtual environment, created with a computer simulation, makes it possible to study several variants of the same workplace at the same time and to make further modifications relatively easily. Furthermore, because there is no need to use an existing workplace (nor any actual objects), it is possible to adapt workplaces while they are still being designed. This facilitates creating workplaces tailored to the needs of people with disabilities, thereby enabling their employment.

2. METHODOLOGY

This research aims to develop a method of adapting workplaces for workers with motion disability with computer simulation and virtual reality techniques. This is a two-step task. Firstly, a person's ability to work is analyzed with a computer human model with applied restraints caused by their disability. Then all necessary modifications of the workplace are proposed and introduced. In the second step, research in a virtual reality environment is carried out with the participation of a person with a disability. Their task is to assess the adjusted workplace and propose additional modifications reflecting comfort of work and personal preferences.

To analyze the ability to work by a person with disability at workplaces thus prepared, a computer human model was created with a visualization of maximal arm reach and preferred working space (Gedliczka et al, 2001; EN ISO 14738:2008). Its basic geometry was based on the 50th percentile of male and female population (Gedliczka et al, 2001; EN 547-3:1996+A1:2008). However, this model can be used to reflect the measurements of any person with restraints caused by their disability. Modifications can be introduced to reflect the needs of a specific person, but also of a model person representing a group of people with disabilities. The model consists of a chain of rigid bodies (corresponding to segments of human bodies) connected with joints with applied constraints. Visualizations of maximal arm reach and preferred working space are calculated according to these constraints and the length of the body segments.

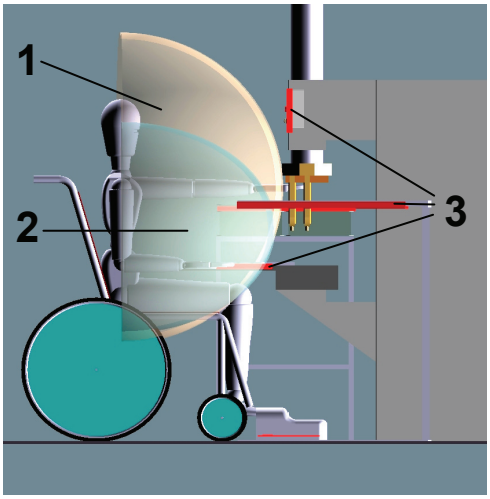


Figure 1. *Computer model of a person in a wheelchair with a visualization of maximal arm reach (1), preferred working space (2) and accessible working areas of the workplace (3).*

Special software, the Troll, was developed as part of this study, too. It can be used to operate virtual environments and the computer human model. It has the form of a graphical editor that makes it possible to import CAD models and to assemble them into a virtual workplace. The human model is imported into such a working environment. All body segments can be scaled to reflect the person's measurements, and the constraint in all joints can be modified according to their disability restrictions. In further work an automatic scaling tool will be implemented. It will then be possible to generate a basic human model according to basic parameters such as body height and weight. However, it will still be necessary to adjust this model to the measurements and constraints of the person concerned.

In the next step, a visualization of maximal arm reach and preferred working space is generated. It is calculated on the basis of the geometry and the constraints of the model. After this step, the model is placed in the virtual workplace and can be moved to each area of the work cycle. In this way, designers can analyze

©2010 ICDVRAT; ISBN 978 07049 15022

whether all areas to be accessed during work are in the range of the person concerned and whether all areas where work is done more permanently are in the preferred working space. They can also evaluate if the worker will be able to access easily the necessary areas of the working environment, which is especially important for people in wheelchairs. The collision detection mechanism, which has been built into the Troll, makes those analyses easier. They result in suggestions of ways to modify workplaces so that they meet the needs of disabled people.

In the second phase, people with disabilities will take part in tests involving virtual reality. With this in mind, an additional module was developed for the Troll, to make stereoscopic visualization of a virtual workplace possible. This will be done with either a quad-buffer feature of some video adapters for devices with one video input or a dual video source rendering for devices with two inputs (one for each eye). All necessary operations can be programmed using the Troll's scripting features. The goal of this research will be to assess the results of the first phase (proposed modifications) and to suggest further modifications that should reflect individual needs. For this task, yet another feature was added; it is now possible to record in a log file various parameters such as the position and rotation of selected virtual work-related objects and trackers. This information can be used to calculate work efficiency, the accuracy of the performed tasks and the number of the worker's moves, leading to an evaluation of various variants of the modified workplaces.

A separate module was developed to help implement the modifications proposed by a disabled worker. It makes controlling the Troll engine via a TCP/IP network possible. Thus, all objects can be modified during the simulation.

The Troll has been built on the Open Source Ogre 3D rendering engine for visualization; physics is supported by the Bullet Physics Engine.

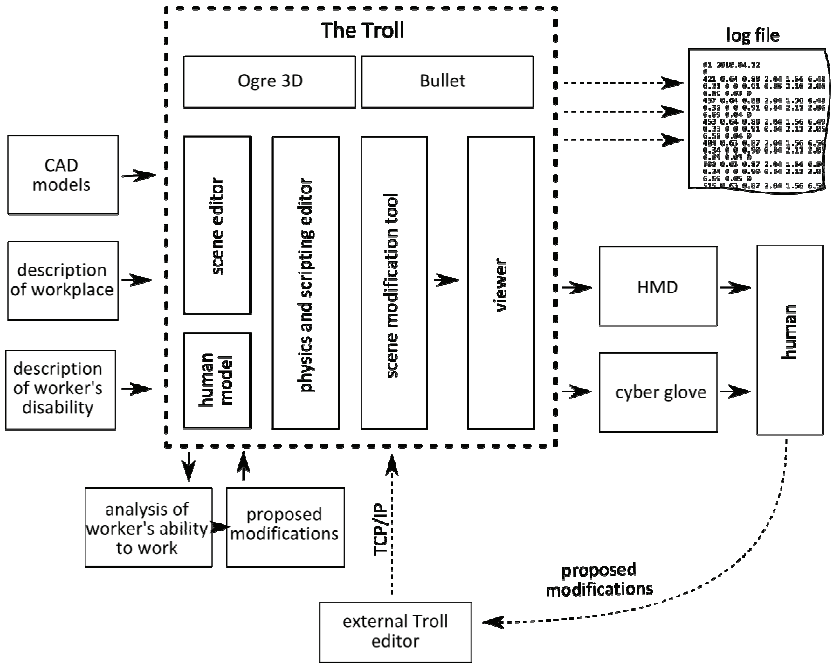


Figure 2. *Functional diagram of the Troll software. Notes. HMD – head mounted displays.*

The following equipment is used to access the virtual reality environment:

- eMagin (USA) Z800 head mounted displays to visualize 3D scenes; it is small and light, so it hardly restricts movement;
- a pair of 5DT (USA) Data Gloves 14 Ultra with 14 sensors to move objects in the virtual reality environment;
- Polhemus (USA) Liberty magnetic tracking with a long range transmitter to move around the environment. Three sensors are used to capture and record positions and rotations of the hands and the head. An additional sensor is attached to the wheelchair to visualize its movement and check for collisions with objects in the virtual workplace.

©2010 ICDVRAT; ISBN 978 07049 15022

3. FIRST STAGE OF RESEARCH

The procedure and the tools described in section 2 were tested at four real-life workplaces for workers with disabilities, located in two different companies. They were workplaces with a welding machine, a grinding machine and two sites for manufacturing rubber products (such as gloves and rubber pipes). Various workers with various disabilities were actually employed at each of these workplaces, so for the purposes of this research these workplaces were adapted for people from the following groups (one person per workplace):

- workers in wheelchairs,
- workers with a disabled right upper extremity,
- workers whose disability coincides with short stature.

Even though the methodology, software and models described here make it possible to consider people with multiple restrictions related to their disabilities, it was decided that the workplaces would be prepared for people with single disabilities only. For each of those groups of disabled people a sample person was selected and a human model was adjusted to their measurements and disability. A model of a wheelchair was also created, with the main geometry based on a typical wheelchair (it can be modified to reflect other models as well). For each model a visualization of maximal arm reach and preferred working space was generated.

In the first phase all important objects at selected workplaces and their placement were measured, work procedure was videoed. In the next step, computer models of all objects important for working at these workplaces were created. In the case of some equipment CAD models were available (provided by the manufacturer), but for most objects models had to be created on the basis of field measurements. All CAD models were prepared in CATIA and imported into Blender modelling software, where complete workplaces were assembled and textures were applied. A thus prepared scene was transferred then to the Troll. Next, work performed at each workplace was analyzed (on the basis of the videos and other collected information) and all areas that should be reached during work were selected and marked.

Figure 3. *Site for manufacturing rubber products: real (left-hand side) and virtual (right-hand side) working environments.*

Computer human models with applied maximal arm reach and preferred working space were placed in virtual working environments and necessary adaptations were analyzed. The results are as follows:

- in all four workplaces 22 zones that had to be accessed during work were identified,
- 13 of those workplaces could not be accessed by the people with disabilities selected for each workplace,
- people in wheelchairs had no problems moving around in any of the workplaces.

In all zones where access was not possible, modifications of workplaces were proposed. In most cases it was necessary to move the actuators or other operating device, in two cases rearrangement of the workplace was necessary. All modification were implemented in the virtual workplaces.

4. SECOND STAGE OF RESEARCH

In the next, currently on-going stage of the project, research that involves virtual reality is carried out. A person with a disability (like earlier) is asked to access a virtual reality environment with immersive virtual reality equipment and to simulate work. This will allow the experimenters to assess the proposed

©2010 ICDVRAT; ISBN 978 07049 15022

modifications. In the next step, further modifications will be proposed according to the preferences of the disabled workers. These modifications will focus on ergonomics. The modified workplace will be assessed by measuring the performance of work and by considering the disabled worker's opinion.

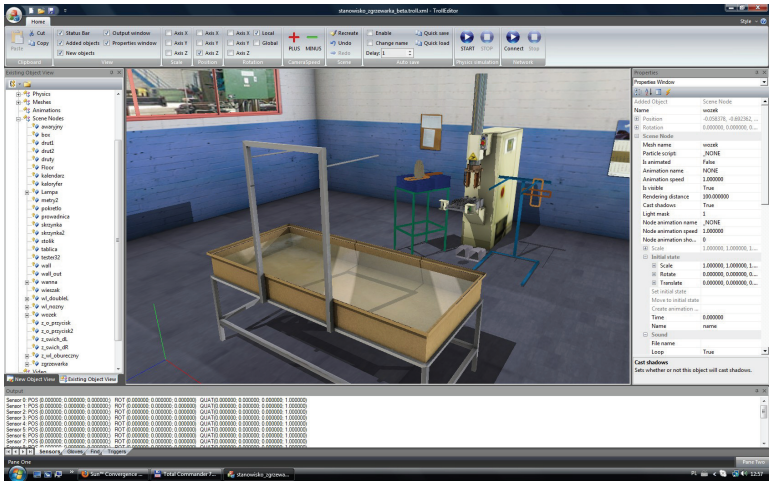


Figure 4. *Workplace with a welding machine in the Troll editor.*

Twelve disabled people from aforementioned groups will participate in this research. They will access a few variants of each workplace: an unmodified one, one with earlier modifications and one with modifications introduced according to their measurements. There will also be one or more additional variants of the workplace, reflecting the opinion of the person studied. There will be twofold evaluation of all variants:

- the efficiency of work, accuracy of performed tasks and movements done during work will be measured;
- a subjective evaluation of work places and each modification will be done with a questionnaire was prepared in cooperation with psychologists.

Each person will spend in the virtual environment approximately 270 min during 3 days of tests. To minimize discomfort after long exposure to immersive virtual reality, one session will take no longer than 30 min, with 20-min breaks in between.

5. CONCLUSIONS AND FURTHER WORK

The results of the first stage of the study show that computer simulation can be used to determine if a worker with a disability can accee all important areas of a workplace and to propose necessary modifications. A virtual environment makes simple, one-step modifications possible. The second stage will consist in verifying the proposed methodology through research with people with disabilities and virtual reality .

The Troll will be developed further to increase its capabilities and ease of use. There are plans to implement an automatic tool for scaling the computer human model. The user will provide information such as gender, body mass and body weight, and the human model will be scaled according to that information. As a result, the user will obtain a basic human model, which will have to be adjusted to the measurements of a person. Ways of analyzing maximal and optimal loads for upper extremities in various points of the arm reach area is another problem. A tool for this task was partially implemented in the current version of the Troll on the basis of Gedliczka et al (2001); however, Gedliczka et al's data on maximal and optimal loads were collected for ergonomic purposes and concern only the 5th percentile of males and females. What is more, these loads are described for the sagittal plane only. That is why this tool was not used in this research. Additional research must be conducted to fully implement an analysis of load for other cases, too.

Acknowledgements: This paper has been prepared on the basis of the results of a task carried out within the scope of the National Programme "Improvement of Safety and Working Conditions", partly supported — within the scope of research — in 2008–2010 by the Ministry of Science and Higher Education. The Central Institute for Labour Protection – National Research Institute is the Programme's main co-ordinator.

6. REFERENCES

D H Ambrose, J R Bartels and A J Kwitkowski (2005), *Mining Roof Bolting Machine Safety: A Study of the Drill Boom Vertical Velocity*. Department of Health and Human Services, Centres for Disease Control and Prevention, NIOSH report IC 9475.

Blender 3D graphic application, *http://www.blender.org*

P Budziszewski, A Grabowski, J Jankowski and M Milanowicz (2010), Wykorzystanie technik rzeczywistości wirtualnej do wspomagania projektowania stanowisk pracy [The use of virtual reality techniques in designing workstations], *Proc. XIV Szkoła Komputerowego Wspomagania Projektowania, Wytwarzania i Eksploatacji*, Jurata Poland.

Bullet physics engine, *http://bulletphysics.org*

A Chłoń-Domińczak and D Poznańska (2007), *Promocja zatrudnienia na otwartym rynku pracy. Proponowane działania w Polsce* [Promotion of employment in the open labor market. Proposed activities in Poland], International Labour Organization, Budapest, Hungary.

V G Duffy, P W Ng Parry and A Ramakrishnan (2004), Impact of a simulated accident in virtual training on decision-making performance, *International Journal of Industrial Ergonomics*, **34**, *4*, pp. 335–348

EN 547-3:1996+A1:2008 *Safety of machinery — Human body measurements — Part 3: Anthropometric data.*

EN ISO 14738:2008 *Safety of machinery — Anthropometric requirements for the design of workstations machinery* (ISO 14738:2002, including Cor 1:2003 and Cor 2:2005).

P Foster and A Burton (2003), Virtual reality in improving mining ergonomics, Application of Computers and Operations Research in the Minerals Industries (APCOM), *South African Institute of Mining and Metallurgy.*

K Fukaya, T Nakamura and S Mannen (2003), *Development of Excavator Accident Simulator*. National Institute of Occupational Safety and Health (NIOSH), Japan, Special Research Report SRR-No28-8.

A Gedliczka, P Pochopień, A Szklarska and Z Welon (2001), *Atlas miar człowieka, dane do projektowania i oceny ergonomicznej* [An atlas of human measures, data for design and ergonomic assessment], Centralny Instytut Ochrony Pracy, Warszawa, Poland.

M Milanowicz and P Budziszewski (2010), Wykorzystanie technik symulacji komputerowej do rekonstrukcji wypadków przy pracy o charakterze mechanicznym [The use of computer simulation techniques in reconstructing occupational accidents involving mechanics], *Proc. XIV Szkoła Komputerowego Wspomagania Projektowania, Wytwarzania i Eksploatacji*, Jurata, Poland.

T S Mujber, T Szecsi and M S J Hashmi (2004), Virtual reality applications in manufacturing process simulation, *Journal of Materials Processing Technology, 155–156,* pp. 1834–1838.

Z Nivolianitou, O N Aneziris and KNasios (2006), Virtual Reality applications for improving safety in the process industry, In *Safety and Reliability for Managing Risk* (Guedes Soares & Zio, Eds), Taylor & Francis, London.

OGRE 3D (Object-Oriented Graphics Rendering Engine), *http://www.ogre3d.org*

VIRTHUALIS – Virtual Reality and Human Factors Applications for Improving Safety, *http://www.virthualis.org/*

T Winkler, D Michalak, S Bojara and Ł Jaszczyk (2006), Zastosowanie technik wirtualnych w rekonstrukcji przebiegu wypadków w górnictwie [The use of virtual reality techniques in reconstructing mining accidents], *Maszyny Górnicze, 1*, pp. 41-44.

©2010 ICDVRAT; ISBN 978 07049 15022

Listening to complexity: blind people's learning about gas particles through a sonified model

O Lahav[1], S T Levy[2]

[1]School of Education, Tel-Aviv University,
Ramat-Aviv, Tel-Aviv, ISRAEL

[2]Faculty of Education, University of Haifa,
Mount Carmel, Haifa, ISRAEL

[1]lahavo@post.tau.ac.il, [2]stlevy@construct.haifa.ac.il

ABSTRACT

Students who are blind have been integrated at public schools with sighted students. Because most of Science Education curriculum resources are based on visual representations such as diagrams, charts, models (real and digital), and exploration in science laboratories, students who are blind are lack in participating and collecting the information from first hand. The current research project is based on the assumption that the supply of appropriate information through compensatory sensory channels may contribute to science education performance. In the research system - Listen to complexity system the user is interacting with dynamic objects in a real life scenario.

1. INTRODUCTION

Students who are blind have been integrated at public schools with sighted students for more than 60 years, and they are required to complete the same curriculum and examinations as sighted students. Because most of the science education curriculum resources are based on visual representations such as diagrams, charts, models (real and digital), and exploration in science laboratories, students who are blind are lacking in participating and collecting the information firsthand. In the last 40 years and longer, manuals were written on how to teach science to students who are blind and visually impaired (Dion, Hoffman, & Matter, 2000; Hadary & Cohen, 1978; Koenig & Holbrook, 2000; Kumar, Ramassamy, & Stefanich, 2001; Willoughby & Duffy, 1989). However, there is little research about how to apply these curricula and their influence on student learning. As a result of the lack of accessibility to educational science material, students are left out or getting the information secondhand (Beck-Winchatz & Riccobono, 2008). As a result of the IDEA97 legislation in 1997, public schools in the United States are required to integrate disabled students within the curriculum. This act has had far-reaching effects for people with disabilities, as it expands their academic skills and knowledge to a wide variety of opportunities. There is a need to support science education research and science teachers with tools and educational materials, which allows the instruction of students who are blind equitable opportunities relative to sighted students. The current research project is based on the assumption that the supply of appropriate information through compensatory sensory channels may contribute to science education performance.

We propose to give students who are blind equal access to the science classroom, allowing the students who are blind to interact in a research group with science education materials and to collect data independently as participants. Other research (Wies et al., 2001, Farrell, Baldyga, Erlandson, 2001) that has focused on science resources for blind and visually impaired individuals has also recommended using alternative sensory channels such as audio and haptic interfaces. These studies have used audio feedback such as text-to-speech in order to read written material that appears on a website or used a tactile map or a haptic mouse to deliver only a 2D spatial representation.

Auditory assistive technologies include recorded or synthesis voice, earcons, and sonification. However more research and development is need for efficient echolocation feedback. The speech audio includes text-to-speech software and print-to-speech reading machine (e.g., Kurzweil Reading Machine). Over the years several auditory technologies have been developed for people who are blind especially in the field of orientation and mobility, for example, Sonicguide (Warren and Strelow, 1985); Kaspa (Easton and Bentzen, 1999); the vOICe system, which transforms a live image to sound by using a live camera and image-to-sound

©2010 ICDVRAT; ISBN 978 07049 15022

renderings (Meijer, 1992); talking signs, embedded sensors in the environment (Crandall, Bentzen, Myers, Mitchell, 1995); virtual sound display (Loomis, Golledge & Klatzky, 1998; Loomis, Marston, Golledge, & Klatzky, 2005); activated audio beacon by using cell phone technology (Landau et al., 2005); Miniguide (by GDP Research, 2005); Palmsonar (by Takes Co., 2007); Personal Guidance System (PGS), based on satellite communication (Golledge, Klatzky & Loomis, 1996, Golledge, Marston, Loomis, & Klatzky, 2004); remote infrared audible signage and haptic pointer interface based on PGS (Marston, Loomis, Klatzky, Golledge, Smith, 2006); sound-based VE systems (Sánchez, Noriega & Farías, 2008); and a VE based on audio and haptic feedback for rehabilitation and spatial learning of unknown environments (Lahav & Mioduser, 2004).

A few systems were developed specifically for learning purposes, such as Talking Tactile Tablets (TTT) based on audio and 2D tactile materials (By TouchGraphics). This technology allows students who are blind to interact with 2D images such as geographic maps, solar system, math and science diagrams, (Landau et al., 2005) and the Line Graphs (Ramloll et al, 2000), which is based on auditory and haptic feedback, to study math. All the technologies above allow the user to interact with a stationary object, and some of these technologies are based on a set-up scenario. Contrary, in the Listen to Complexity (L2C) system the user interacts with dynamic objects in a real life scenario.

Complex systems are made up of many elements, such as molecules in this study, which interact among themselves and with their environment. They are not regulated through central control yet; they self-organize in coherent global patterns (Holland, 1995). NetLogo (Wilensky, 1999a) is a programming language for creating agent-based models of complex systems, such as those used in the current study. Exploring such models in chemistry (visual representations) has been shown to be effective in helping students gain a deeper understanding (Ardac & Akaygun, 2004; Kozma, 2000; Levy & Wilensky, 2009b; Snir et al., 2003; van der Meij & de Jong, 2006).

Unfortunately, systems are notoriously difficult to comprehend. Complex systems challenge our understanding, calling for reasoning at different description levels (micro- and macro-), considering interactions among elements, and relating between events taking place at the same time in different parts of the system. Several biases sway people's reasoning about systems: assuming central control even when it does not exist (Resnick & Wilensky, 1993), assigning behavior at one of the system's levels to another (Wilensky & Resnick, 1999), a focus on the system's parts and structure at the expense of attending to its function and mechanisms (Hmelo-Silver & Pfeffer, 2004), and a tendency to view causal relations as a consecutive rather than parallel chain of cause and effects (Chi, 2005). These difficulties point to the importance of educational support in making sense of systems.

Several innovative learning environments have been designed to help people overcome the above-reported biases and understand complex systems, such as constructing and exploring computer models (Ioannidou, Repenning, Lewis, Cherry & Rader, 2003; Klopfer, 2003; Levy & Wilensky, 2009a; Resnick, 1994; Wilensky, 1995, 1997ab, 1999a; Wilensky & Reisman, 2006; Wilensky & Resnick, 1999) and role-playing participatory simulations (Colella, 2000; Klopfer, Yoon & Perry, 2005; Resnick & Wilensky, 1998; Soloway et al., 2001; Wilensky & Stroup, 1999ac, 2000). In this study, we have offered blind people an opportunity to explore computer models through the modality of sound, possibly making such information.

This study grows out of the Connected Chemistry activities that use computer-based models for learning the gas laws and kinetic molecular theory in chemistry (Levy & Wilensky, 2009a). It views chemistry from an "emergent" perspective, how macroscopic phenomena result from the interaction of many submicroscopic particles.

Our research questions:

(1) What differences are found between the answers to the pre- and post-test?

(2) What processes accompany the learning of the various concepts?

(3) Does the sonified representation of the gas model enable people who are blind to mentally model the gas system?

2. THE ENVIRONMENT

The learning environment is comprised of three elements: a computer model, a recorded voice guide to exploring the model, and the interviewer. The computer model is a modified version of a model that was originally created for the GasLab curriculum (Wilensky, 2003) and then adapted for the Connected Chemistry curriculum (Levy & Wilensky, 2009a). The model includes gas particles in a container into which particles are added through a valve. The particular adaptation of the model for this study involves

©2010 ICDVRAT; ISBN 978 07049 15022

sonification of variables, locations and events. For example, the speed of a single particle is represented by an oboe whose pitch corresponds with its value.

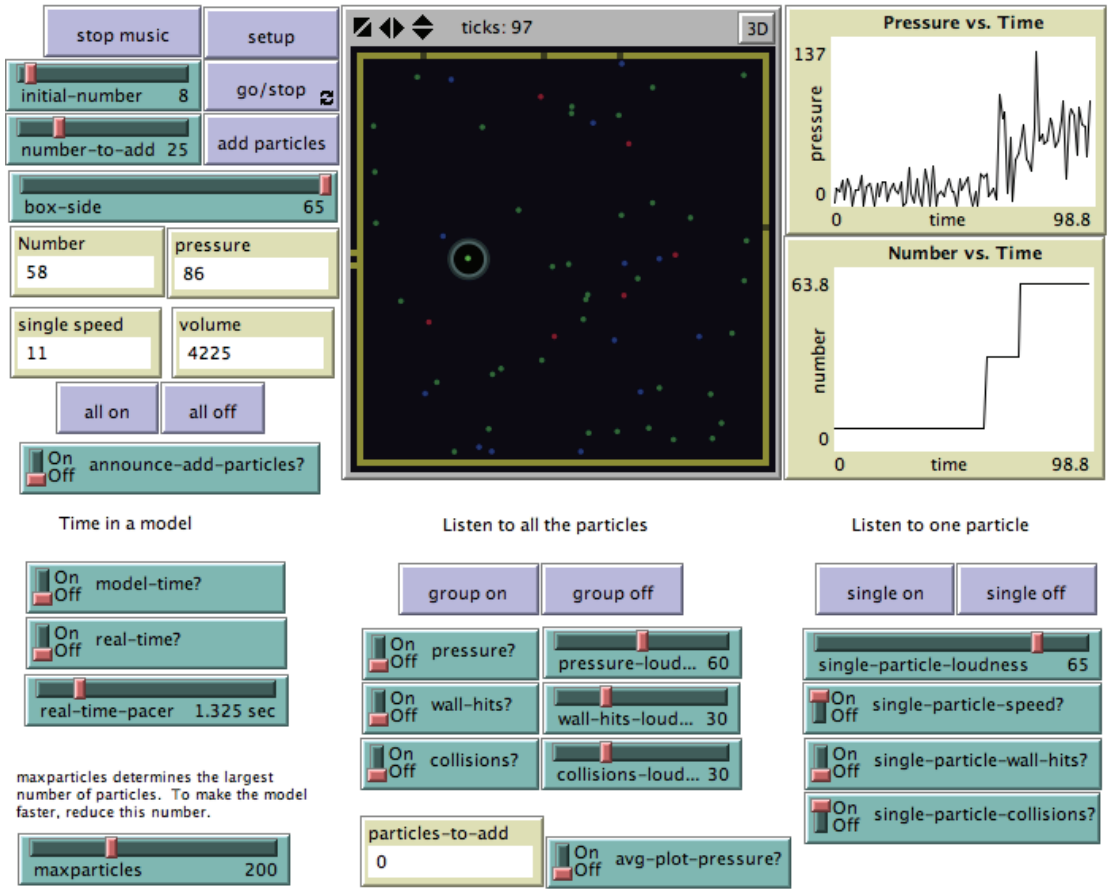


Figure 1. *User Interface.*

3. METHOD

2.1 Participants

The subject, R., is forty-four years old. He has been totally blind since the age of 16 and has been using computers for 25 years. R. learned science in middle school and in college, including about phases of matter and kinetic theory of gases. R. never used computer-based models or simulation.

2.2 Variables

Four dependent variables were defined:

Correctness of Model. The correctness of the model (100%) with respect to the scientific model, or as an alternative, a mental model (doesn't know, correct, and alternative)

Partiality of Correct Model. Number of correct components (out of 7)

Components of Model. This variable includes 17 components: particles, straight line motion, change in direction results from hitting wall, change in direction results from hitting other particles, change speed does not result from colliding with the wall, change in speed (either up or down) results from colliding with other particles, particles move about randomly, other, more particles lead to greater frequency of collisions, greater density of particles lead to greater frequency of collisions, smaller volume lead to greater density of particles, smaller volume lead to greater frequency of collisions, smaller/greater volume lead to average speed doesn't change, smaller volume lead to distance between collisions decreases, smaller volume lead to more frequent speed changes, more particles lead to more speed changes, and more/less particles lead to same average speed.

©2010 ICDVRAT; ISBN 978 07049 15022

Levels in the System. To understand the participant's views of the system as complex, a number of features are noted. In this variable, we noted the levels that are described and whether they are connected (doesn't know, macro, micro, and both macro and micro). In addition to this variable, we will look at interactions, based on the codings in the variable 'components of model' for the interactive dimensions.

2.3 Research instruments

The main instruments used in the study were:

NetLogo 4.1 (Wilensky, 1999). The application included a gas lab based on auditory feedback.

Research Protocol. This research protocol included four tasks: feeling and pumping up a bike tire, listening to a particle (wall hits, speed, particle-particle collisions, collisions and speed, wall hits and speed), listening to air pumping in (a particle's collisions with other particles when air pumps in, a particle's speed when air pumps in), and changing volume. The four tasks included 20 open-ended questions before and after each task. No feedback was provided by the researcher.

In addition, a set of three instruments was developed for the collection of quantitative and qualitative data:

Background Questionnaire. This questionnaire included 17 questions about the participant's personal information (for example, name, age, gender, cause of blindness, age of onset blindness, visual ability), and science educational background (during middle school, high school, or later).

Pre- and Post-Test Questionnaire. Identical pre- and post-test questionnaire, this questionnaire included an overview about simulated air particles inside a bicycle tire and ten questions (Levy & Wilensky, 2009b).

Recorded Observations. The participant's behavior was video-recorded during the task.

2.4 Procedure

The design of this study was a pre-test-intervention-post-test. The study was carried out in four stages. At the first stage, the study was introduced, consent was obtained, and background information was recorded. The second stage was the administration of the pre-test. The third stage included the intervention: (a) feeling and pumping up a real bike tire; (b) using the model to learn about a particle; and (c) using the model to learn about air pumping in. This intervention was followed by a post-test in the fourth stage. The study, which lasted 2.5 hours, was video-recorded.

4. RESULTS

Research Question One: What differences are found between the answers to the pre- and post-test?

R. shifted from 3/7 correct answers in the pre-test to 5/7 in the post-test. Improvement consisted of including gas in a bike tire representation, particle-particle collisions, extending understanding of pressure to novel situations, and random space-filling distribution of particles. Concepts that were not learned were particles moving randomly with no higher intentions and collisions between particles being distinct from collisions with the wall – the first results in speed change, but the latter does not.

Research Question Two: What processes accompany the learning of the various concepts?

R. started out with a fully macroscopic view of the system and an understanding that collisions among particles increase their speed while their collisions with the wall decreases their speed. Figure 3 describe the score regarding R.'s responses to the questions in the activity. These are graded as "don't know" (1), alternative understanding (2) and correct understanding (3).

Through the activities, his focus shifted to the submicroscopic particles and his misconstrued concepts came up against contradictions. In some cases, his reasoning shifted to a correct understanding; in others, he shifted into confusion, a preliminary phase to resolution. An example of a shift to a new understanding targets an understanding of energy exchange when two particles collide: "I think that when they collide, the speed increases… I haven't a clue. I thought I had a pattern but it didn't work out… yea, I think it was up the speed and then it slows down as a result of the collision." A significant bridging of submicro- and macro-levels is seen in his understanding that pumping up more particles into the container does not change their average speed even though the speed changes more frequently. Understanding the random distribution of the particles location and speed did not improve from pre- to post-test. However, we can see his budding observation of such randomness when he tries to makes sense of durations between collisions: "Yea, I guess when it hit two particles back-to-back in a short period of time, it did not seem to repeat that… Besides that, it did not seem to be regular intervals. Umm, I mean between hitting different particles."

©2010 ICDVRAT; ISBN 978 07049 15022

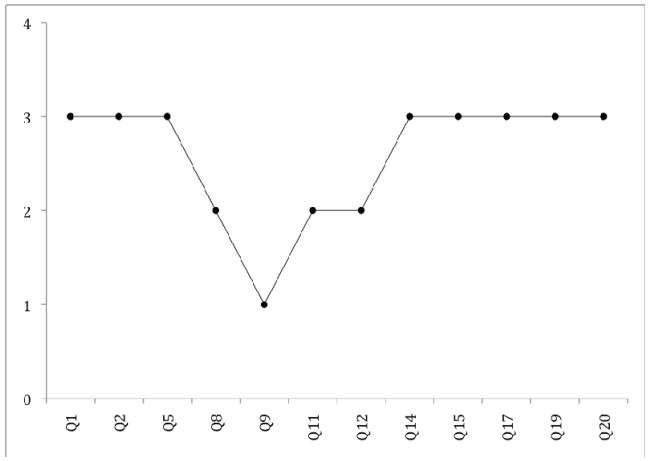


Figure 2. *Progression of subjects' responses to the activity questions in terms of fit to the correct scientific knowledge*

Research question 3: Does the sonified representation of the gas model enable people who are blind to mentally model the gas system?

We note R.'s utterances that refer to making sense of the representations. For example, when listening to the particle hit the different walls of the container: "I can tell you that at some points it ricochets back and forth between the opposite sides." As for integrating two sounds, after listening and connecting collisions and speed changes, he responds positively. In summarizing the activity, R. states "Basically you're learning a new language."

R. suggests several improvements: changing the pitch of the wall hits so that the walls can be better distinguished using no more that 5-6 tones so that the user can keep track of all the information, shifting control to the user regarding model manipulation, tone setting, and changing the speed. In addition, he supports adding an option to use recorded voice to state which wall is being hit.

We have seen significant shifts in R.'s understanding of the chemical complex system he explored through the sonified model. Some changes resulted in reconceptualization of the domain and others reflect his understanding that his previously construed concepts are not validated in the model. At the time of the conference, detailed results from the actual study as well as preliminary conclusions regarding design and learning issues will be presented.

5. REFERENCES

D Ardac and S Akaygun (2004). Effectiveness of multimedia-based instruction that emphasizes molecular representations on students' understanding of chemical change. *Journal of Research in Science Teaching 41*, pp. 317–337.

B Beck-Winchatz and M A Riccobono (2008). Advancing participation of blind students in science, technology, engineering, and math. *Advances in Space Research, 42*, pp. 1855-1858.

M T H Chi (2005). Commonsense conceptions of emergent processes: Why some misconceptions are robust. *Journal of the Learning Sciences, 14*(2), pp. 161-199.

V Colella (2000). Participatory simulations: Building collaborative understanding through immersive dynamic modeling. *The Journal of the Learning Sciences, 9*, pp. 471–500.

W Crandall, B L Bentzen, L Myers and P Mitchell (1995). *Transit accessibility improvement through talking signs remote infrared signage, a demonstration and evaluation*. San Francisco, CA: The Smith-Kettlewell Eye Research Institute, Rehabilitation Engineering Research Center.

M Dion, K Hoffman and A Matter (2000). *Teacher's manual for adapting science experiments for blind and visually impaired students.* Retrieved October 7, 2004, from http://www.tsbvi.edu/ Education/Manual 12. Doc

R D Easton and B L Bentzen (1999). The effect of extended acoustic training on spatial updating in adults who are congenitally blind. *Journal of Visual Impairment and Blindness, 93* (7), pp. 405-415.

B Farrell, D D Baldyga, and R Erlandson (2001). Force feedback mouse used for a physics experiment. *NSF*

©2010 ICDVRAT; ISBN 978 07049 15022

2001 report: Engineering Senior Design Projects to Aid Persons with Disabilities, Chapter 21, Wayne State University 308-309. [http://nsf-pad.bme.uconn.edu/2001/Wayne%20State%20University.pdf]

R G Golledge, R L Klatzky and J M Loomis (1996). Cognitive Mapping and Wayfinding by Adults Without Vision. In *The Construction of Cognitive Maps* (J Portugali, Ed.), Netherlands: Kluwer, pp. 215-246.

R G Golledge, J R Marston, J M Loomis and R L Klatzky (2004). Stated preferences for components of a Personal Guidance System for nonvisual navigation. *Journal of Visual Impairment and Blindness, 98*, pp. 135-147.

D Hadary and S Cohen (1978). *Laboratory science and art for blind, deaf and emotionally disturbed children*. Baltimore, MD: University Park Press.

C E Hmelo-Silver and M G Pfeffer (2004). Comparing expert and novice understanding of a complex system from the perspective of structures, behaviors, and functions. *Cognitive Science, 28*, pp. 127-138.

J H Holland (1995). *Hidden Order: How Adaptation Builds Complexity*. Cambridge, MA: Helix Books/Addison-Wesley.

A Ioannidou, A Repenning, C Lewis, G Cherry and C Rader (2003). Making Constructionism Work in the Classroom. International *Journal of Computers for Mathematical Learning, 8*(1), pp. 63-108 (special issue on agent-based modeling).

E Klopfer (2003). Technologies to support the creation of complex systems models – using StarLogo software with students. *Biosystems, 71*(1-2), pp. 111-122.

E Klopfer, S Yoon and J Perry (2005). Using palm technology in participatory simulations of complex systems: A new take on ubiquitous and accessible mobile computing. *Journal of Science Education and Technology, 14*(3), pp. 285-297.

A Koenig and M Holbrook (Eds.). (2000). *Foundations of education, Volume 2: Instructional strategies for teaching children and youths with visual impairments* (2nd ed.). New York: AFB Press.

R B Kozma (2000). The use of multiple representations and the social construction of understanding in chemistry. In *Innovations in science and mathematics education: Advanced designs for technologies of learning* (M J Jacobson and R B Kozma Eds.), Lawrence Erlbaum, New Jersey, London, pp. 11-46.

D Kumar, R Ramassamy and G Stefanich (2001). Science for students with visual impairments: Teaching suggestions and policy implications for secondary learners. [Electronic version]. *Electronic Journal of Science Education, 5,* pp. 1-9.

O Lahav and D Mioduser (2004). Exploration of Unknown Spaces by People who are Blind, Using a Multisensory Virtual Environment (MVE). *Journal of Special Education Technology, 19*(3).

S Landau, W Wiener, K Naghshineh and E Giusti (2005). Creating Accessible Science Museums With User-Activated Environmental Audio Beacons (Ping!). *Assistive Technology, 17,* pp. 133–143.

S T Levy and U Wilensky (2009a). Crossing levels and representations: The Connected Chemistry (CC1) curriculum. *Journal of Science Education and Technology, 18*(3), pp. 224-242.

S T Levy and U Wilensky (2009b). Students' Learning with the Connected Chemistry (CC1) Curriculum: Navigating the Complexities of the Particulate World. *Journal of Science Education and Technology, 18*(3), pp. 243-254.

J M Loomis, R G Golledge and R L Klatzky (1998). Navigation system for the blind: Auditory display modes and guidance. *Presence: Teleoperators and Virtual Environments, 7*, pp. 193-203.

J M Loomis, R G Golledge, R L Klatzky and J R Marston (2007). Assisting wayfinding in visually impaired travelers. In *Applied Spatial Cognition: From research to cognitive technology* (G L Allen, Ed.), Mahwah NJ: Lawrence Erlbaum Associates, pp. 179-202.

J R Marston, J M Loomis, R L Klatzky, R G Golledge and E L Smith (2006). Evaluation of spatial displays for navigation without sight. *ACM Transactions on Applied Perception, 3*, pp. 110-124.

P B L Meijer (1992). An Experimental System for Auditory Image Representations. *IEEE Transactions on Biomedical Engineering, 39(*2), pp. 112-121.

Ramloll Yu, Brewster, Riedel, Burton, Dimigen (2000). Constructing Sonified Haptic Line Graphs for the Blind Student: First Steps. *ASSETS'00*, November 13-15, 2000, Arlington, Virginia.

M Resnick (1994). *Turtles, Termites and Traffic Jams: Explorations in Massively Parallel Microworlds*. Cambridge, MA: MIT Press.

M Resnick and U Wilensky (1993). Beyond the Deterministic, Centralized Mindsets: New Thinking for New

©2010 ICDVRAT; ISBN 978 07049 15022

Sciences. Paper presented at the *annual meeting of the American Educational Research Association*, Atlanta, GA.

M Resnick and U Wilensky (1998). Diving into complexity: Developing probabilistic decentralized thinking through role-playing activities. *The Journal of the Learning Sciences, 7*, pp. 153-172.

J Sánchez, G Noriega and C Farías (2008). Mental Representation of Navigation through Sound-Based Virtual Environments. Paper presented at the *2008 AERA Annual Meeting*, New York (NY), US.

J Snir, C L Smith and G Raz (2003). Linking phenomena with competing underlying models: A software tool for introducing students to the particulate model. *Science Education 87*, pp. 794–830.

E Soloway, C Norris, P Blumenfeld, B Fishman, J Kracjik and R Marx (2001). Log on Education Handheld devices are ready-at-hand. *Communications of the ACM, 44*, 6.

J Van der Meij and T de Jong (2006). Supporting students' learning with multiple representations in a dynamic simulation-based learning environment. *Learning and Instruction 16*, pp.199-212.

D H Warren and E R Strelow (1985). *Electronic spatial sensing for the blind*. Boston, MA, Martinus Nijhoff.

E F M Wies, S O'Modhrain, C J Hasser, J A Gardner and V L Bulatov (2001). Web-based touch display for accessible science education. In *Haptic HCI 2000* (S Brewster and R Murray-Smith Eds.), LNCS 2058, pp. 52-60.

U Wilensky (1995). Paradox, programming and learning probability: A case study in a connected mathematics framework. *Journal of Mathematical Behavior, 14*, 2.

U Wilensky (1997). What is normal anyway? Therapy for epistemological anxiety. *Educational Studies in Mathematics, 33(*2), pp. 171-202. (Special Issue on Computational Environments in Mathematics Education)

U Wilensky (1999). *NetLogo*. Center for Connected Learning and Computer-Based Modeling, Northwestern University. Evanston, IL. http://ccl.northwestern.edu/netlogo.

U Wilensky (2003). Statistical mechanics for secondary school: The GasLab Modeling Toolkit. International *Journal of Computers for Mathematical Learning 8*(1): pp.1-41. Special issue on agent-based modeling.

U Wilensky and M Resnick (1999). Thinking in levels: A dynamic systems perspective to making sense of the world. *Journal of Science Education and Technology 8*(1), pp. 3-19.

U Wilensky and W Stroup (1999). Learning through participatory simulations: Network-based design for systems learning in classrooms. *Computer Supported Collaborative Learning Conference (CSCL '99).* Stanford University, California: December 12-15, 1999.

U Wilensky and W Stroup (2003). Embedded complementarity of object-based and aggregate reasoning in students developing understanding of dynamic systems. Paper presented at the *annual meeting of the American Educational Research Association*, Chicago, IL, April 1-5.

U Wilensky and K Reisman (2006). Thinking Like a Wolf, a Sheep or a Firefly: Learning Biology through Constructing and Testing Computational Theories -- an Embodied Modeling Approach. *Cognition and Instruction, 24*(2), pp. 171-209.

D Willoughby and S Duffy (1989). *Handbook for itinerant and resource teachers of blind and visually impaired students*. Baltimore, MD: National Federation of the Blind.

©2010 ICDVRAT; ISBN 978 07049 15022

Using augmented reality to support the understanding of three-dimensional concepts by blind people

C Kirner[1], T G Kirner[2], R S Wataya[3], J A Valente[4]

[1,2]Federal University of Itajubá,
Itajubá, BRAZIL

[3]Adventhist University of São Paulo,
São Paulo, BRAZIL

[4]State University of Campinas,
Campinas, BRAZIL

[1]*ckirner@unifei.edu.br*, [2]*tgkirner@unifei.edu.br*, [3]*sussumu2911@gmail.com*, [4]*jvalente@unicamp.br*

ABSTRACT

Seeing and describing real and imaginary three-dimensional scenes from the observer's viewpoint is an intuitive activity for non-impaired people, but it is difficult for congenitally blind people, once it involves abstract concepts for them, such as: perspective, depth planes, occlusion, etc. This paper discusses the problem related to understanding three-dimensional concepts by blind people and presents physical environments and procedures supported by an augmented reality tool in order to help blind people to understand, describe and convert three-dimensional scenes into two-dimensional embossed representations, like painting. To verify how the blind people can acquire those concepts, we developed an augmented reality application, working as an audio spatial tutor to make the perspective learning process easy. That application was tested with ten congenitally blind people, who understood the perspective concepts and made comments about the experience. Finally, we discuss the learning method and technical aspects, pointing out directions to improve the augmented reality application and ways to release it.

1. INTRODUCTION

Access to information depends mainly on visualization to understand complex structures based on texts, graphics, representations, pictures, animations, videos, etc. In this way, the main problem caused by blindness is the absence of visualization requiring another senses to replace the vision function, such as touch and sound (IMS GLC, 2002), whose use depends on different technologies and application domains.

The first approach to give information to blind people involved embossed writing, Braille writing and talking books (recorded speeches). Using computer and new technologies, many other resources came to help blind people, such as: screen readers, audio browsers, digital talking books, multimodal hypermedia interfaces, synthetic human speeches, non-speech sounds, tactile graphic displays, video description, haptic devices, etc. (Spirkovska, 2004). The newest technologies, involving virtual reality and augmented reality (Kirner and Kirner, 2008; Azuma, 1997), extended the concept of information for blind people, giving them access to static and dynamic spatial information in real-time with the use of GPS, three-dimensional (3D) accelerometers, computer vision, sounds and speeches. Nowadays, blind people can see with their ears, recognizing sound patterns associated with things and scenes through augmented reality technology (Meijer, 2010; Layar, 2010), using notebook or mobile phone.

By another side, there are many specific domains of information that depends on modes of presentation that fall outside the bounds of pure text (IMS GLC, 2002). Among those contents, there are: Mathematics, sciences, charts, diagrams and tables, Geography and maps, arts, etc. For those areas, 3D concepts involving perspective, depth perception, shadow, occlusion, etc. are too important but difficult to understand by congenitally blind people.

Sighted people use perspective and related concepts intuitively during the vision process, but they need to learn how to represent 3D onto a flat plate. Those concepts appear in photos, realistic pictures and in textual or oral description of real scenes. Congenitally blind people, who never had experienced vision, present

©2010 ICDVRAT; ISBN 978 07049 15022

difficulty to understand depth in a picture converted into embossed print or draw. They understand a scene made by 3D models (miniature) and the surfaces of the models or the front plane of a picture.

This paper has some questions to be answered, such as: (i) How can blind people learn 3D concepts aiming to be able to convert explored 3D environments into pictures? (ii) How can we develop a spatial audio tutor with augmented reality technology to make easy the understanding of 3D concepts by blind people?

This paper presents an augmented reality application working as a spatial audio tutor to make easy the understanding of perspective and related concepts without the necessity of a specialist to conduct the learning process. The system uses audio streams associated with spatial positions that can be activated by blind users. To test the application, ten congenitally people have used it, making comments about the learning of perspective concepts.

2. RELATED WORK

Visual concepts for blind people, like perspective draw and spatial cognition representation from several viewpoints, are themes studied and experimented by scientists who are searching technologies and methods to allow teaching and learning spatial representation.

Kennedy, Gabias and Heller (Cheadle, 1990) have discussed the relations about pictures and the blind, showing that is possible for the blind to understand and represent space as he/she is intensively exposed to tactile drawings.

How can a congenitally blind recognize an embossed picture by touch if he/she did not have experience with objects and space representation? (Kennedy, 1993) The answer for this question involves studies of vision properties, geometry, depth, projection, occlusion, scale, edges, vertices, corners, surfaces and color shades, among others, by blind people (Kennedy and Juricevic, 2006; Heller and Kennedy, 1990; Klingenberg, 2007). It is a difficult process, as it involves abstract concepts for congenitally blind people, but these concepts can be learned and trained, giving them better conditions to recognize real and imaginary world representations and even represent them (Heller et al, 2005).

Pictures for listening (Othman and Levanto, 1996) was a project developed with a partnership, involving an art university, a museum, an association of visually handicapped and a broadcasted company, aiming to plan and produce packages containing relief pictures, booklets in bold type and Braille and sound pictures. A sound picture is an audio mixed with narrated text and sound effects.

Otherwise, projects like ACCESS (Petrie et al, 1996) have explored the access to information in computer hypermedia system including effective representation of information in Braille, synthetic speech and sound with support for navigation and use by blind students.

However, it is important to associate sound, speech and force feedback to points in 3D space to allow blind people to explore spatial environment with feedback. Virtual reality provides a model to explore 3D virtual space with feedback, as it allows spatial control by the user through special devices, such as: gloves, haptic devices, etc. The blind user could explore the virtual environment, sensing or touching things by sound or force feedback and navigating on it from different heights and viewpoints (Brewster and Pengelli, 1998; Inman et al, 2000). The advantage of this approach is the freedom to choose height, speed, scale and other parameters when the user explores the virtual environment. The disadvantage of that approach is that the virtual environment is not real and untouchable with free hands.

To overcome the disadvantage of virtual reality environments, augmented reality can be used to superimpose virtual environments over real environments allowing the transference of sound properties from virtual objects to real objects, which are coincident. In this way, when the user touches a real object with his/her hand, the augmented reality system can identify that collision activating a specific sound or speech. Figure 1 shows the activation of a 3D object with its sound in an augmented reality application using cards (markers) interaction under a webcam.

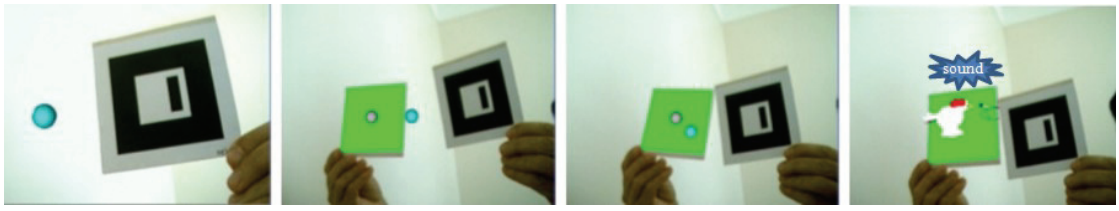


Figure 1. *Activating sound in an augmented reality application based on cards.*

©2010 ICDVRAT; ISBN 978 07049 15022

Products, such as Layar (Layar, 2010) and The vOICe (Meijer, 2010), are exploring augmented reality systems associated with GPS and spatial orientation to produce sounds and speeches related to the point of interest or patterns of the scene. Projects, such as: Hear & There (Rozier et al, 2000), Guide by Voices (Lyons et al, 2000) and Outdoor Augmented Reality Environments (Goudeseune and Kaczmarshi, 2001), also explore sounds and speeches in outdoor environments with augmented reality technology.

3. ENVIRONMENT TO UNDERSTAND THREE-DIMENSIONAL CONCEPTS

Blind people have natural perception skills for touching and recognizing miniature spatial environments and embossed front pictures, according to Figure 2. So, it is necessary to find a way to convert those representations to embossed two-dimensional (2D) representations showing mainly depth and scale variation of objects in a 3D scene.

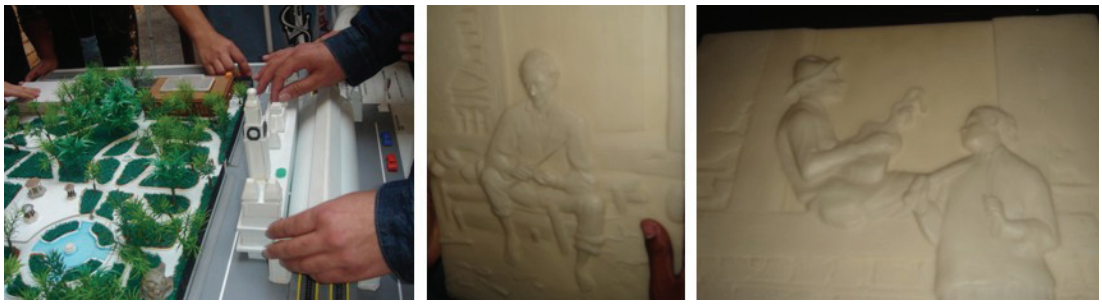
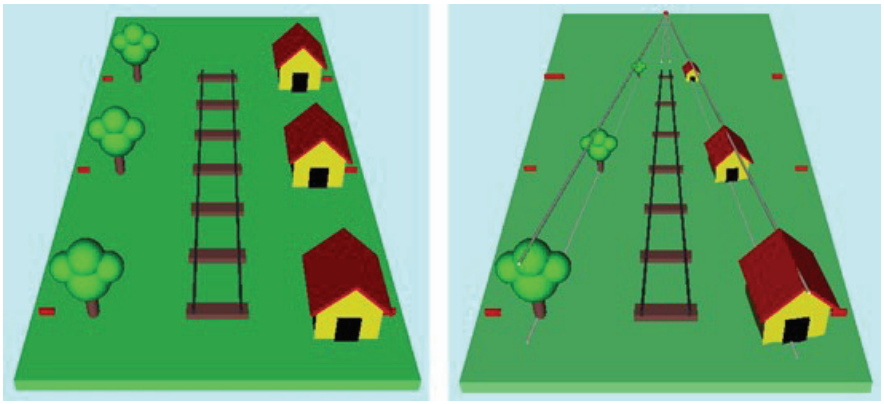
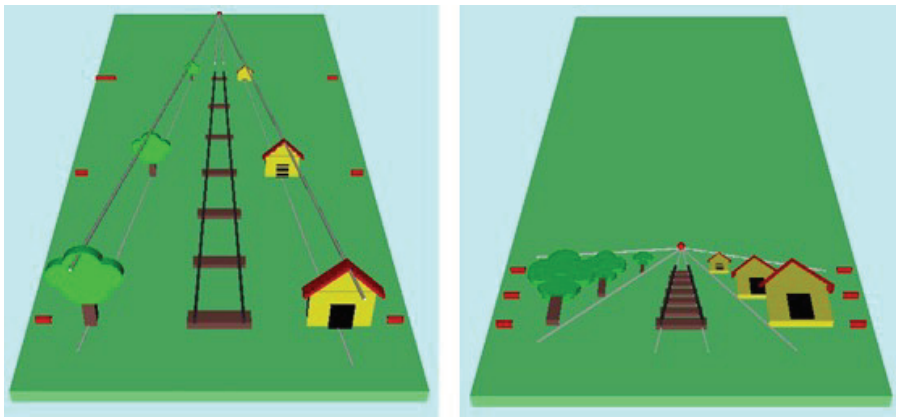


Figure 2. *Handling a miniature environment and embossed front pictures.*

We decided to use a method based on four environments, according to Figure 3, to do that conversion.



a) Miniature 3D environment. b) 3D perspective representation.



c) 3D Perspective with embossed models. d) Perspective embossed representation.

Figure 3. *Four environments used to learn 3D concepts.*

©2010 ICDVRAT; ISBN 978 07049 15022

The four environments are the following:

i) Miniature 3D environment using simplified 3D models of houses, trees and railroad;

ii) 3D perspective representation of the first environment using different scales of those 3D models, depending on the depth, and showing the convergence lines going from the observer to a specific point. Big models are closed to the observer and small models are far from the observer considering a specific viewpoint;

iii) Representation of the second environment using embossed 2D models replacing the 3D models. Besides the different scales, the 2D models present different thickness, so that closed models are thick and distant models are thin. To get the embossed representation, all 2D embossed objects need to be laid on the picture plane;

iv) 2D embossed representation of the third environment compressing the depth planes, or relocating the convergence point. This representation is an embossed picture.

Using the four representations, blind people can explore the environments to learn 3D concepts and a technique aiming to convert real or mental scenes in an embossed picture.

In the first environment (miniature 3D environment), the idea is to allow blind people to explore a specific miniature 3D environment in order to be familiar with the objects in the scene.

In the second environment (3D perspective representation), the blind users could learn concepts of perspectives, including depth planes, different scales of the same object depending on depth, convergence lines, etc.

The third environment (3D Perspective with embossed models) only replaces the miniature objects by equivalent embossed objects with different thickness depending on its position in the scene. On the first depth plane, embossed object representations are thick and on the last depth plane, embossed object representations are thin. This environment is intermediary between the second and fourth and prepares objects to be placed in the fourth environment.

In the fourth environment (Perspective embossed representation), when the blind user would be already familiar with the miniature environment and its respective perspective 3D representations, he/she could pick up the scaled thick or thin embossed objects to adjust them laid on a flat (2D) plate, creating an embossed picture. This action creates an embossed picture so that objects with specific thickness participate on specific depth planes. In this case, occlusions can appear when a laid object from one depth plane overlaps another object from other depth plane.

Once a blind user understands the whole representation process, converting a miniature 3D environment into a 2D embossed picture, he/she can execute the reverse process converting embossed pictures into real or mental 3D environments. In this way, a blind user can express himself/herself in graphical arts, creating and explaining embossed pictures for his/her visually impaired colleagues and non-impaired people.

4. AUGMENTED REALITY TOOL TO SUPPORT BLIND PEOPLE IN LEARNING PROCESS

An augmented reality tool to support blind people in learning process must present characteristics and satisfy certain requirements, such as: spatial positions defined by authors, virtual objects with associated sounds, simple installation, easy authoring, authoring independent of programming, intuitive use, tolerance in touching spatial positions.

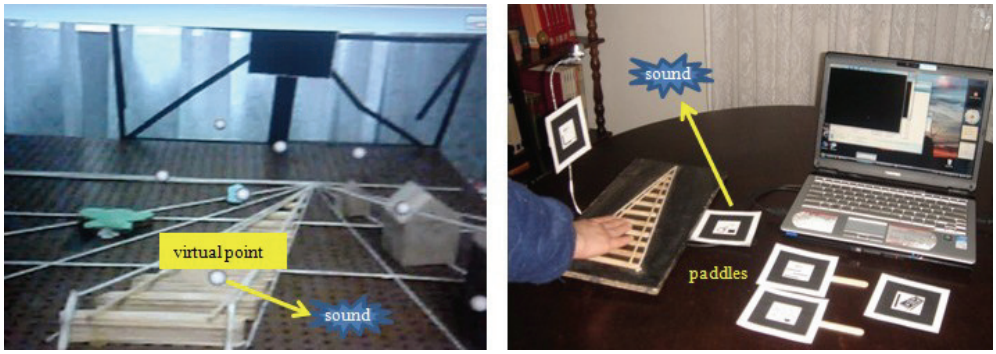
In order to support blind people in learning 3D concepts, we developed an augmented reality tool named "Augmented Reality Authoring Tool for Non-Programmers - ARAS-NP" (Kirner and Santin, 2010) using ARToolKit (Kato and Billinghurst, 1999). With this tool, an author can develop applications for blind users defining and associating touchable spatial positions with virtual objects and sounds (Figure 4a). Virtual objects are used to guide the authoring while sounds are used by blind users. To develop applications, the user can use paddles and functions keys (Figure 4b). To explore applications, blind users can manipulate one or two markers to activate points and hear their sounds.

4.1 Structure of the Augmented Reality Environment

The augmented reality environment, as considered in this work, presents virtual objects with their respective sounds on spatial points defined by the developer (Figure 5a). In order to be touchable by the blind user, each spatial point has an embossed point on the physical board or over the physical objects of the environment, in

©2010 ICDVRAT; ISBN 978 07049 15022

which audible information will be retrieved. Each spatial point can have associated with it only one pair of virtual object and its sound or a sequence of several pairs, which will be activated by blind user one by one when he/she place a marker over the embossed point.



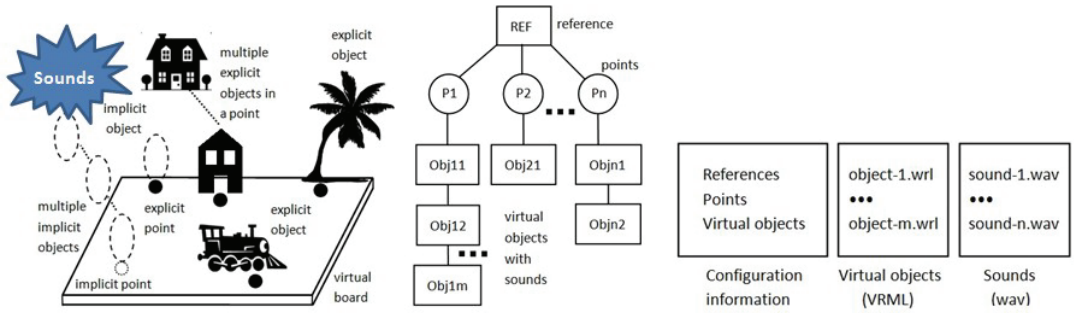
a) Spatial points. b) Paddles and function keys.

Figure 4. *Augmented reality environment for blind users.*

Moreover, the augmented reality environment can be customized after authoring through copying, moving and deleting specific points and virtual objects with their respective sounds.

4.2 Data Structure and Folders

The data structure of the augmented reality environment to be authored comprises reference markers, which have associated virtual boards, and their respective elements (points, virtual objects and sounds) that appear on the board, according to Figure 5b. Those elements must be placed in folders (Figure 5c) that the developer needs to manipulate to create the augmented reality environment.



a) Augmented world. b) Data Structure. c) Folders.

Figure 5. *Structure of the augmented reality environment.*

The tool has three folders: configuration, virtual objects and sounds. Details about folders will be explained in the next subsection.

4.3 Authoring Interface

In the authoring phase, the application can be developed in two ways: i) visual actions carried out under a webcam (Figure 6a) complemented by editing file; ii) editing files associating points, objects and sounds. The resources, which are used to create points and associated objects with sounds, comprise action markers, keyboard keys, mouse buttons, configuration files and folders.

4.3.1 Action Markers. Action markers allow tangible actions interacting with spatial points and virtual objects (with sounds) placed on or over a virtual board, according to Figure 6. They can be used during authoring or utilization phases.

In the augmented environment, spatial points and virtual objects have visible or invisible virtual spheres associated with them, whose radius can be adjusted by the user, allowing variation in precision during the selection process. Each marker also has an associated visible virtual sphere that can collide with the virtual spheres of points and virtual objects.

©2010 ICDVRAT; ISBN 978 07049 15022

An action marker can select a point or virtual object and carry out a specific function on it. The movement of an action marker in the board area allows collision of its virtual sphere with the virtual sphere of a point or virtual object of the augmented environment, selecting or deselecting the point or virtual object and activating the respective sound. The gesture of the action marker, like inclination, occlusion, or time remained selecting, can execute actions on the selected point or virtual object, activating sounds.

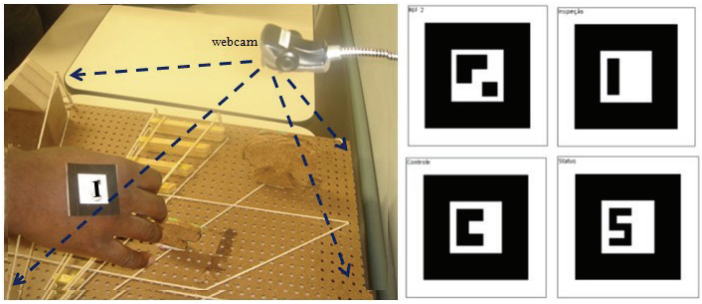


Figure 6. *Action marker working under a webcam.*

These markers are: inspect (show the virtual object of the selected point, activating its sound); control (show the next virtual object of a list associated with the point, activating its sound); transport (take a virtual object from a position to another one); erase (delete a point and its associated virtual object with sound or list); status (show a virtual plate with information about the system); lock (lock or unlock remote actions on virtual objects associated with a point, being useful in collaboration tasks); copy (replicate a virtual object with sound to be placed in a position of other reference environment), and path (allow the creation and visualization of a visual path from a position to another one).

Simple applications can be developed with no markers and used with one or two markers and simple few configuration files, making easy the development.

4.3.2 Keyboard Keys and Mouse Buttons. Specific keyboard keys and mouse buttons activate complimentary actions working alone or in conjunction with action markers.

Those keys and buttons can activate or deactivate: visualization of points and virtual objects, activating the respective sounds; remote operations; path creation; status visualization; persistence of virtual objects; etc. They can also control the position and radius of the sphere associated with the marker, aiming to improve precision and performance in the selection process. As less is the radius of the sphere, more difficult is the selection, but in some cases, when there are many closed points, it is necessary to get better precision to be successful in the operation.

Mouse buttons actuating in conjunction with the inspector marker allow visual creation of points in the augmented environment and in the respective file that can be configured later by editing.

4.3.3 Configuration Files. Configuration files must be created by the user or edited from the sample files available in the authoring system or from previously created files in the visually points creation process.

Those files contain authoring information supplied by the user in order to prepare the augmented reality environment for use or for complimentary visual configuration. The configuration files are:

- *Reference Marker Information (one file for each reference marker).* This file contains: address, position, orientation, scale and sound of the virtual board and address of the points list associated with the marker;
- *Points List of a Reference Marker (one file for each reference marker):* This file contains: position and list of virtual objects (with sounds) associated with the point 1; …; position and list of virtual objects (with sounds) associated with the point n.
- *Virtual Objects List of a Point (one file for each point).* This file contains: address, position, orientation, scale and sound of the virtual object 1; …; address, position, orientation, scale and sound of the virtual object m.

A simple text editor should be used to create or edit configuration files.

4.3.4 Folders. Folders are resources filled by non-programmer developer, which contain useful information to create the augmented reality environment. There are three folders: configuration information, virtual objects, and sounds, according to Figure 3.

©2010 ICDVRAT; ISBN 978 07049 15022

Configuration information folder contains configuration files related to reference markers, points, virtual objects and behavior vectors. Virtual object folder contains VRML three-dimensional models, found on the Internet or created by three-dimensional authoring software. Sounds folder contains sounds associated to virtual objects found in sounds libraries or recorded by the developer.

The contents of folders must be filled before using, but they can be modified during the utilization phase, mainly some configuration files.

The system also has commands to save and recover it in order to allow the interruption of the authoring process, which can be continued later.

4.4 Utilization Procedures

In the utilization phase, the blind user should manipulate the augmented reality using tangible actions with specific markers. The most used is the inspector marker, which allows the exploration of the environment, placing it over embossed spatial points and hearing their respective sounds. The use of control marker allows the exploration of sounds from the list of pairs (virtual object and sound) associated with a specific point.

However, aiming at giving more power to the system, it is possible to reconfigure the environment during the utilization phase, changing the initial situation of the authoring.

Besides, the system has a specific marker (collaborative ref marker), which allows the networking among several remote users, implementing collaborative tasks. Although potentially interesting, we did not think to use this feature with blind users, exploring sounds in this phase.

5. DEVELOPMENT AND TEST OF AN AUDIO SPATIAL TUTOR

In order to test the learning process of 3D concepts by blind people using augmented reality environment, we used the ARAS-NP tool to develop an audio spatial tutor, which allows blind people to activate spatial points to render sounds and speeches. The application contains spatial points with sounds in two levels (Figure 7): the first level uses the Inspection Marker to activate each spatial point rendering sounds and speeches giving general information about that point; the second level uses the Control Marker to activate each spatial point rendering sounds and speeches from a sequence giving detailed information about that point.

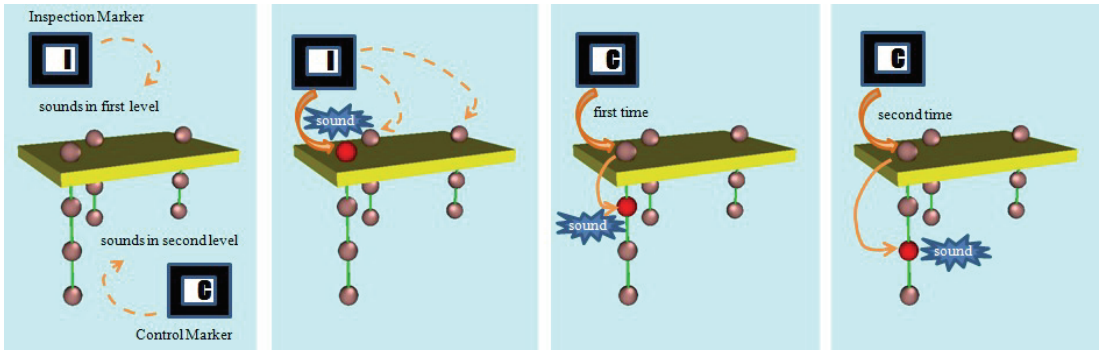


Figure 7. *Activating spatial points with sounds in two levels.*

5.1 Learning 3D Concepts with the Audio Spatial Tutor

The four physical environments used to explain 3D concepts involve 3D miniature environment with 3D objects, 3D perspective representation with scaled 3D objects, 3D perspective representation with embossed scaled 2D objects and 2D perspective representation with laid on embossed scaled 2D objects with occlusion. Those environments were enriched with embossed points over the physical board and objects from which blind users can hear audible information when using the Audio Spatial Tutor configured for each environment. The configured Audio Spatial Tutor contains spatial virtual points, which are coincident with specific spatial physical points of each environment, so that each point contains audio information, which can be activated by certain markers generating sounds. When the blind user explores the physical environment and senses an embossed physical point, he/she places an action marker (Inspector or Control) over the point hearing the audible information, which explains 3D concepts about that situation.

To make the user interaction easy, the markers can be adjusted on a finger or over the hand since the application calibration takes each situation in account.

©2010 ICDVRAT; ISBN 978 07049 15022

Blind users have freedom to explore those environments by themselves acquiring knowledge in an independent way and working on a personalized rhythm and navigation in different sequences.

5.2 Testing the Audio Spatial Tutor

To test the Audio Spatial Tutor, we selected a set of ten congenitally blind persons with the following characteristics: four participants were graduate students and six were professionals; seven participants were female and three were male; the participant's age varied from 20 to 53 years.

After a brief instructional session, all participants were exposed to the interactive augmented reality environment, which was composed by the four physical environments augmented with the configured Audio Spatial Tutor.

In the first environment (3D miniature environment), the blind users recognized the physical objects (trees, houses, railroad, etc.) using their natural perception (touching) and hearing information about the scene and objects when they placed markers on the embossed spatial points of the environment.

The second environment (3D perspective representation with 3D models) introduced 3D concepts, such as: perspective, convergence lines, depth planes, viewpoints, etc., using objects with different scales, depending on the spatial depth plane in which the object was placed.

In the third environment (3D perspective representation with 2D embossed models), the depth plane was represented by the thickness of the 2D embossed objects, allowing the perception of distance with different objects and different sizes.

Finally, the fourth environment (2D perspective representation with laid on 2D embossed models) is an embossed with laid on objects. In this case, when embossed 2D objects from the third environment are laid on, some of them can overlap others and the overlapped part of the thin objects need to be cut off to be adjusted. The resulting environment is an embossed picture that can be recognized by vision and by touch, once it contains perspective scaled objects whose thickness represents the depth planes of the scene.

In all four environments, the Audio Spatial Tutor delivered general or detailed audio information to the blind users on each embossed point allowing them to learn perspective concepts and the perspective representation process starting from a miniature environment and reaching an embossed picture (Figure 8).

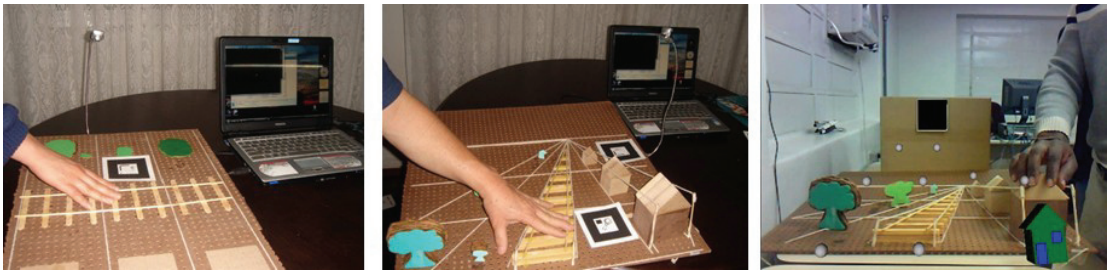
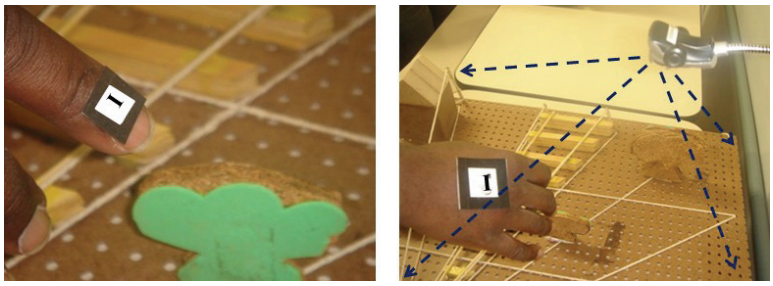


Figure 8. The *Audio Spatial Tutor in action.*

In order to activate sounds on spatial points, blind users tried to use small size markers on the finger and big size markers over the hand. The webcam was placed on the top of the environment pointing to down (Figure 8).



a) Marker on a finger. b) Marker over the hand.

Figure 9. *Using markers to help the environment exploration.*

Due to the camera quality, light conditions, sizing of the colliding sphere of points and other factors, the blind participants presented initially some difficulty to activate the sounds delaying about one minute to do

©2010 ICDVRAT; ISBN 978 07049 15022

that. With the improvement of system calibration and user experience, the time to activate the sounds went down to some seconds.

With this process, congenitally blind users learned how to represent a miniature environment from a viewpoint (front, side, rear, etc.), once they were only familiar with the top representation before. Other important learned concepts were scaled objects depending on the distance of the observer and occlusion of objects depending on the depth planes, which are unusual and abstract for congenitally blind people.

When the blind user is well-acquainted with the perspective representation process, he/she can hear and understand oral descriptions of a 3D scene or picture, such as: what is closed to or far from the observer, what is small or larger depending on the real size and the distance of the observer, what is occluded by other things, etc. Moreover, the blind user can make oral descriptions of real scenes that he/she sensed or imaginary scenes.

At the end of the test, blind users made declarations about the experience, pointing out the acquired knowledge, emphasizing the understanding of embossed or described paintings, the understanding of oral description of real scenes and the ability to draw perspective pictures representing real or imaginary 3D scenes.

6. CONCLUSIONS

We presented and discussed the problem related to understanding three-dimensional concepts by congenitally blind people, showing a learning method, an augmented reality application to support learning (Audio Spatial Tutor) based on audio and spatial positions and an augmented reality tool used to develop the application.

The understanding process occurs in four phases involving a 3D miniature environment, a 3D perspective representation based on scaled 3D objects, a 3D perspective representation based on scaled embossed objects and a 2D embossed picture.

Although 3D concepts are intuitive for non-impaired people, they are abstract concepts for congenitally blind people that can be understood and learned. The congenitally blind people acquired concepts, such as: perspective representation, depth planes, convergence lines, viewpoint, scale dependent on the distance from observer, objects occlusion, etc.

Ten congenitally blind people tested the learning system based on spatial positions and sounds (Audio Spatial Tutor) acquiring 3D concepts in order to be able to perceive, understand and produce embossed pictures representing real and imaginary 3D scenes. After learning 3D concepts, blind people were able to understand descriptions of 3D scenes narrated by non impaired people and to do the same thing increasing his/her social inclusion.

Blind users explored the four learning environments, touching the embossed points and objects and hearing information about them in the 3D and perspective representation context. Using markers on a finger or over a hand under the webcam, the blind user could activate sounds and speeches explaining the concepts related to perspective representation of 3D scenes.

The augmented reality support works as an audio spatial tutor in which sounds and speeches have one or more instances able to be activated in the same point by markers.

Moreover, augmented reality applications for blind users, emphasizing sounds on spatial points, can be authored by non-programmers making easy this task. Blind users can also be authors preparing sound and speech records and configuring files using screen readers.

The Audio Spatial Tutor is being prepared to be distributed for any language as a pack containing: i) plans of the four environments with draws for implementation in foldable paper, or tables with size specifications to be used with other materials like wood; ii) ARAS-NP tool; iii) configured Audio Spatial Tutor for the four environments without speeches; iv) texts of speeches in English to be translated to and recorded in any language; v) free audio recording tool; vi) installing and using instructions and tutorials.

Although the system was conceived to be used by blind people, it can be useful to non-impaired people, who need to learn how to represent perspective draw of 3D scenes.

Finally, we believe that the Audio Spatial Tutor, including the physical environments, learning methods and augmented reality tool can be improved to deal with other abstract concepts for congenitally blind people, such as colors, transparency, shades, etc., giving them better conditions to perceive, represent and describe the world in which they live.

©2010 ICDVRAT; ISBN 978 07049 15022

7. REFERENCES

R T Azuma (1997), A Survey of Augmented Reality, *Presence: Teleoperators and Virtual Environments*, **6** , 4, pp. 355-385.

S A Brewster and H Pengelly (1998), Visual impairment, virtual reality and visualisation, *Proc. of the First International Workshop on Usability Evaluation for Virtual Environments*, Leicester, pp. 24-28.

B Cheadle (1990), Pictures and the Blind, In Future Reflections (B Cheadle, Ed.) *The National Federation of the Blind Magazine for Parents and Teachers of Blind Children*, **9**, 1, Retrieved June 27, 2010 from: http://www.nfb.org/images/nfb/Publications/fr/fr9/Issue1/f090111.html

C Goudeseune and H Kaczmarski (2001), Composing Outdoor Augmented-Reality Sound Environments, *Proc. of the International Computer Music Conference*, Havana, 4pp.

M A Heller and J M Kennedy (1990), Perspective taking, pictures and the blind, *Perception & Psychophysics*, **48**, 5, pp. 459-466.

M A Heller, M McCarthy and A Clark (2005), Pattern Perception and Pictures for the Blind, *Psicologica: International Journal of Methodology and Experimental Psicology*, 26, 1, pp. 161-171.

IMS GLC (2002), *IMS Guidelines for Developing Accessible Learning Applications*, Version 1.0, White Paper, Retrieved June 27, 2010 from: http://www.imsglobal.org/accessibility/accessiblevers/index.html

D P Inman; K Loge and A Cram (2000), Teaching Orientation and Mobility Skills to Blind Chldren Using Computer Generated 3-D Sound Environments, *Proc. of the International Conference on Auditory Display*, Atlanta, pp. 1-5.

H Kato and M Billinghurst (1999), Marker Tracking and HMD Calibration for a Video-based Augmented Reality Conferencing System, *Proceedings of the 2nd IEEE and ACM International Workshop on Augmented Reality*, San Francisco, USA, pp. 85–94.

J M Kennedy (1993), Drawing and the Blind, Yale University Press, New Haven.

J M Kennedy and I Juricevic (2006), Blind Man Draws Using Diminution in Three Dimensions, *Psychonomic Bulletin and Review*, **13**; 3, pp. 506-509.

C Kirner and T G Kirner (2008), Virtual Reality and Augmented Reality Applied to Simulation Visualization, In (J Kisielnicki, Ed.), *Virtual Technologies: Concepts, Methodologies, Tools and Applications*, IGI Global, pp. 897-921.

C Kirner and R Santin (2010), *Augmented Reality Authoring Tool for Non-Programmers (ARAS-NP)*, Retrieved June 27, 2010 from: http://www.ckirner.com/sacra/aras-np/

O G Klingenberg (2007), Geometry: Educational Implications for Children with Visual Impairment, *Philosophy of Mathematics Educational Journal*, **20**, 15, 15 pp.

Layar (2010), *An overview of the Layar platform*, Retrieved June 27, 2010 from: http://site.layar.com/create/platform-overview/

K Lyons; M Gandy and T Starner (2000), Guided by Voices: An Audio Augmented Reality System, *Proc. of the International Conference on Auditory Display*, Atlanta, 12 pp.

P B L Meijer (2010), *Augmented Reality for the Totally Blind*, Retrieved June 27, 2010 from: http://www.seeingwithsound.com/

E Othman and M Levanto (1996), Pictures for listening: Visual arts for the visually handicapped, In (D Burger, Ed.) *New technologies in the education of the visually handicapped*, Colloque INSERM/John Libbey Ltd, 237, pp. 109-118.

H Petrie; S Morley;P McNally; P Graziani and P Emiliani (1996), Access to hypermedia systems for blind students, In (D. Burger, Ed.), *New technologies in the education of the visually handicapped*, John Libbey, London.

J Rozier; K Karahalios and J Donath (2000), Hear&There: An Augmented Reality System of Linked Audio, *Proc. of the International Conference on Auditory Display*, Atlanta, 6 pp.

L Spirkovska (2004), *Summary of tactile user interfaces techniques and systems*, Tech. Report, NASA Ames Research Center, USA, Retrieved June 27, 2010 from: http://ti.arc.nasa.gov/m/pub/905h/0905%20(Spirkovska)%20v2.pdf

©2010 ICDVRAT; ISBN 978 07049 15022

Augmented reality application for the navigation of people who are blind

J Sánchez[1], A Tadres[2]

[1,2]Department of Computer Science
University of Chile, Santiago, CHILE

[1]*jsanchez@dcc.uchile.cl*, [2]*atadres@dcc.uchile.cl*

[1 2]*www.dcc.uchile.cl*

ABSTRACT

A person who is blind can be capable of locating objects and also other people, such as a sighted person, by just using audio cues. In this research we present the design, development and evaluation of ARTAB, a technological assistant for people who are blind that uses Augmented Reality to identify a set of objects in an indoor environment. As a result, we generated audio-based representations that allow a user to determine the position of an object relative to the angle of vision of the video capture device for navigation purposes. The usability testing performed allowed us to detect that it is not trivial to assign sound effects so that the variation of such effects would imply changes in the position of an object. The continual variation of the sound pitch does not generate the contrast necessary for the blind user to be able to obtain a certain kind of information. However, users generally perceive ARTAB as a useful tool for assisting orientation and mobility tasks.

1. INTRODUCTION

Computer science is part of our daily lives and is often invisible to mobile users. One of the new computing applications is directly related to supporting the development of orientation and mobility (O&M) skills in people who are blind.

A person who has a visual disability is clearly at a disadvantage compared to a sighted person, due to the fact that he must cope with a world that has been designed and constructed for by people who can see (Sáenz and Sánchez, 2010). There are several activities in daily life that require the use of vision as the main sense, and that are very difficult to perform through the use of other senses, unless there is some form of external assistance (Lahav and Mioduser, 2008). Such a disadvantage is clear for someone who cannot see.

One activity that may seem simple for many sighted people is navigating throughout the space, in that it is necessary to be constantly collecting information in order to know the place in which one is located and the location of the point to which one wants to go, in order to then make decisions on how to take the optimal route to get there. It is as such that, as a way to help a visually disabled person, the question emerges on how it would be possible to provide the information that a sighed person acquires through vision efficiently.

In providing access to information, it is important to represent such information in a way that is coherent and comprehensible for the person who needs it. In the case of people who are blind, a virtual representation of real space can be created, and they can be made to interact with such a virtual environment. A transfer of what has been learned virtually can then occur, navigating in the real-world environment (Sánchez, Sáenz and Ripoll, 2009). Another option is to take certain contextual information and supply assistance through a technological aide, providing the user with information that allows him to make decisions (Angin, Bhargava and Helal, 2010; Yaagoubi, Edwards and Badard, 2009).

Be it the former or the latter option, the development of an audio-based interface to represent and interact with the real or a virtual environment is feasible. Through the use of audio-based cues, a person who is blind is able to locate objects of interest, just as a sighted person would be able to do (Crossan and Brewster, 2006). The creation of these interfaces requires a careful design, so that the user does not feel saturated with an excessive amount of information (Loomis, Marston, Golledge and Kaltzky, 2005).

©2010 ICDVRAT; ISBN 978 07049 15022

The concept of Augmented Reality (AR) was coined long ago. This concept consists of providing the user with annexed information on the environment, either directly or indirectly, by either visual or auditory means. The elements of this information are augmented by a virtual image created by the computer. To do this, it is possible to take a video image from the real environment and superimpose adequately scaled virtual objects over it, which are oriented in relation to the objects in the real environment in real time (Azuma, Baillot, Behringer, Reiner, Julier and MacIntyre, 2001; Bimber and Raskar, 2005). This can be extended not only to virtual objects represented with 3D models, but to the use of 3D sounds as well (Azuma, 1997; Sodnik, Tomazic, Grasset, Duenser and Billinghurst, 2006), with which the objective of adding extra information to the real context is achieved.

In this research we present the design, development and evaluation of ARTAB, a technological assistant for people who are blind that uses Augmented Reality to identify a set of objects in an indoor environment.

2. ARTAB

The ARTAB software (Augmented Reality Tags for Assisting the Blind) has been designed and developed by using a user-centered methodology (Deutsches Institut fu□r Normung, 1998), working with the end user from the very beginning of the design process, considering his ways of interaction and interests, and making him an active participant in the design and development process. In order to achieve this, usability methodologies were fully used (Nielsen, 1993; Wells, 2006) in the various stages for the design and development of the application.

2.1 Architecture Model

For the design of ARTAB, a development model of mobile applications was used (Sánchez, Sáenz and Baloian, 2007; Sánchez, Flores and Baloian, 2007).

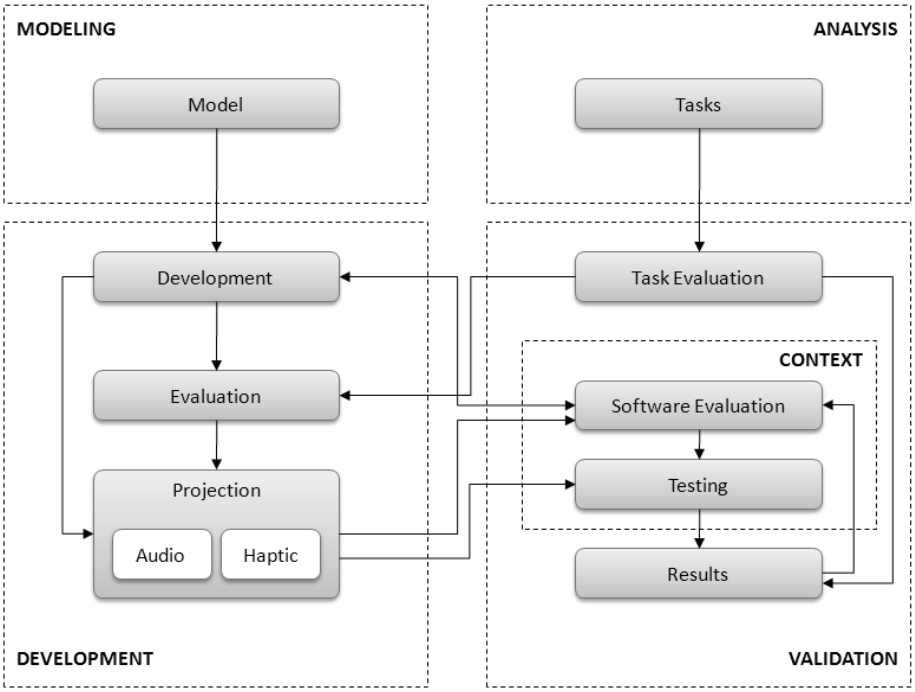


Figure 1. *Model used for the design of ARTAB (*Sánchez, Sáenz and Baloian, 2007).

Modeling: This component corresponds mainly to how the environment that the user will navigate will be represented. To do this, parts of the environment have been marked with special tags for the significant points and objects. These tags will be recorded through a video capture device, and interpreted by ARTAB.

Development: The development process of the system consists of specific stages that allow for the creation of an application that fulfills the proposed objectives. Overall, the application is to be accessible for people with visual disabilities. In the case of ARTAB, accessibility is provided by an audio-based and haptic interface, and by the navigation pad used to ask questions of the system. ARTAB provides information (output) through pre-recorded TTS (Text to Speech) and spatialized audio. The user's interaction with the

©2010 ICDVRAT; ISBN 978 07049 15022

device (input) is performed through his position relative to the camera, regarding the tags and a navigation pad.

The projection determines how the information should be represented through audio, and the mode of interaction. This information is necessary for the system to be functional for the user. In ARTAB the spatial sound heard by the user corresponds to his position relative to the tag, measured by the camera that the user wears. The evaluation implies determining whether or not the system is correct in the data that it evaluates and the information provided to the users.

Analysis: With the purpose of analyzing the use of the system developed, specific tasks had to be designed in order to study the correct impact of the use of the system on the users. To evaluate the usability, tasks involving navigation through places unfamiliar to the users who are blind were designed. The users had to find certain objects, represented by the tags.

Validation: This stage allows for improving the system, redefining the interfaces in order to improve the user's interaction. With the intention to revise the performance of the users on the defined tasks, tests were made that allowed for the correction of errors in the design of the platform. This process was essential for improving the pertinence of the system regarding how the users interact with a mobile system. During this stage, usability evaluations were held in a real-world context that consisted in using the system to evaluate the mode of interaction and the input and output interfaces.

2.2 Interfaces

ARTAB is an application that uses visual tracking, used in Augmented Reality applications, to identify certain objects of interest within a real environment, through the use of a video capture device. The idea is to detect the objects in order to generate a virtual audio-based representation that allows the user to know the objects position within the range of vision allowed by the device.

The application runs on a laptop computer, and prior to its use in the real environment, the important objects in the environment are identified and assigned with a tag, which is a square with a unique monochromatic design (Figure 2). A webcam is situated just on the user's forehead, in order to use neck movements to direct it in a certain direction between the different tags. The user interacts with the application through a small navigation pad.

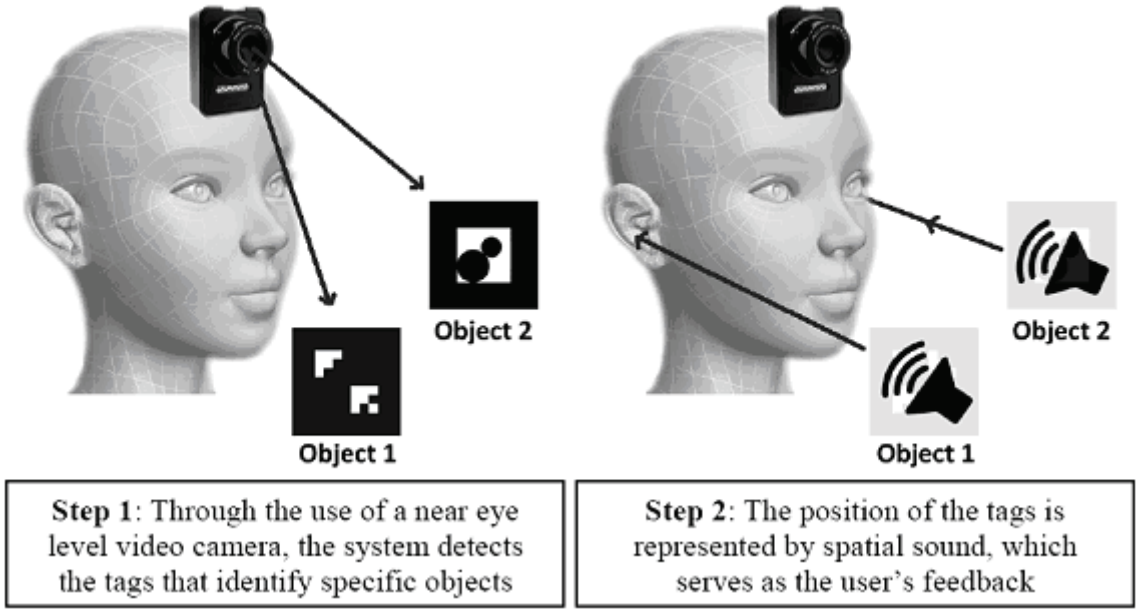


Figure 2. *Overall ARTAB system performance.*

Identification of the tags will only occur within the visual field that the video capture device allows. The image obtained is divided into two, concentric and rectangular sectors (see Figure 3). When a tag is identified within the first sector, a constant and characteristic sound alerts the user of its presence within the visual field. When the user is positioned in the middle, which corresponds to the second sector, he can ask for information on the object by pressing a certain button in the navigation pad.

©2010 ICDVRAT; ISBN 978 07049 15022

Due to the fact that the perception of 3D sound varies depending on the hardware that is used (which is to say that using quadraphonic sound is not the same as using stereo headphones), a representation that allows us to position a sound source in a 3D environment by varying certain properties has been developed. For the horizontal axis, the channel varies by where the constant sound is emitted; the vertical axis varies the pitch of the sound, and the axis that is perpendicular to the observer varies the volume.

Although there are approaches that use tracking to identify objects (Zhang, Ong and Nee, 2009), the idea of this study is to incorporate an audio-based interface that allows the user to obtain information when the objects are right in front of him, without feeling saturated by possible information overload.

We believe that the use of this system, and overall of the audio-based interface, will allow users to identify objects more easily in his own context, in such a way that it is almost like being a user without a visual disability.

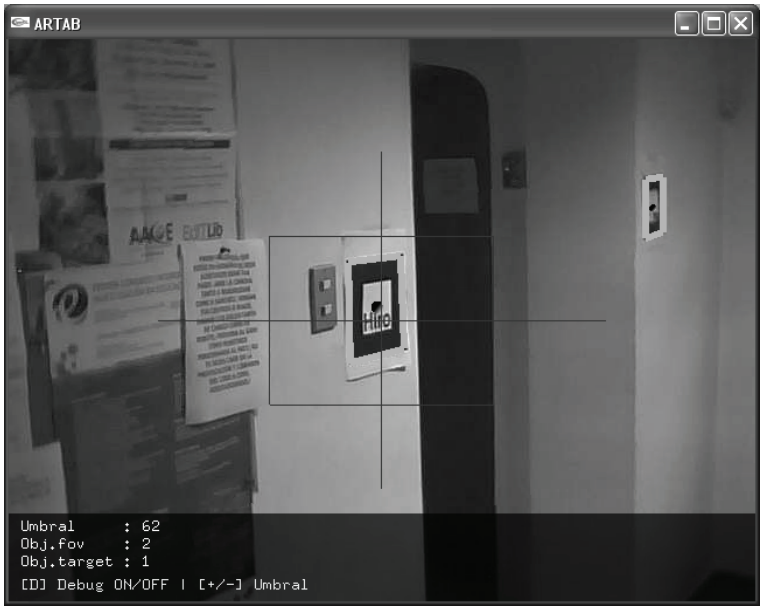


Figure 3. *Graphic interface used by the research team (facilitator), observing the two sectors utilized by ARTAB, When the tag has been identified, the central sector allows the user to ask questions about the object that is in front of him. In being outside, the spatialized sound provides the user with the position of the tag.*

The use of spatial sound is based on previous studies that point out that its use allows for the development of learning and overall cognitive abilities in people who are blind. Several applications use spatial sound to help children to develop navigational and problem-solving abilities. Among these are AbES (Sánchez, Tadres, Pascual-Leone and Merabet, 2009) and AudioDoom (Sánchez and Zúñiga, 2006). Another experience uses stimuli to simulate visual signals in people who are blind, using 3D audio-based interfaces, allowing the users to be able to locate specific points within a 3D space (Sánchez and Sáenz, 2005).

2.3 Development

ARTAB application was developed using Microsoft Visual Studio.NET and C++ programming language, to be used with a Windows XP operating system or newer. This application uses ARToolKit 2.7.1 for tracking and OpenAL 1.1 SDK for 3D sound. A Creative Webcam was used as video capture device, with a resolution of 640 x 480 pixels and a capture rate of 30fps. For testing, we use an Intel Core 2 Duo 2.00GHz and 2 GB of RAM. The installation of the application needs 20 MB of hard disk. The audio output interface was normal headphones without special features.

3. USABILITY EVALUATION

3.1 Sample

For the usability evaluation of ARTAB we have considered a sample of 10 totally blind users with ages that ranged between 15 and 50 years old. All of them lived in the city of Santiago, Chile. The sample was made of 4 women and 6 men. None of them had any other neurological deficits. All of the subjects in the sample are

©2010 ICDVRAT; ISBN 978 07049 15022

users of the JAWS software (which allows users to read the content presented on a computer screen), and are thus accustomed to listening to TTS instructions at a certain speed.

3.2 Instruments

The Prototype Interface Evaluation Questionnaire was used, which allowed us to quantify the degree to which the sounds used in the application were recognizable. This questionnaire asked questions about the quality of the sounds associated with different actions in the simulator, such as object alerts and TTS. As an annex to this questionnaire, an Understandability Questionnaire was applied to the users, which included questions such as: It was possible to know the relative position of the objects? Did you like the sounds used for feedback in the software? Do you think that the software provides enough information? What other kind of information would you add to the software? The idea was to come to gather knowledge about aspects related to orientation and mobility that make up the focus of the software, as well as the use of the controls, the information provided by the software, and the user's navigation in the virtual environment. The results of this evaluation allowed us to redesign and improve the user interfaces.

Once the corrections and redesign of the software had been carried out, the End-User Questionnaire based on Sanchez's Software Usability for Blind Children Questionnaire (Sánchez, 2003) was administered. This questionnaire consists of 14 items for which the users must define to what degree each of them was fulfilled, using a scale ranging from 1 ("a little") to 10 ("a lot"). The results allowed us to evaluate the usability of the software according to the user's satisfaction, using sentences like that "I like the software", "The software is motivating" and "I will use again this software", the freedom of use and control, using sentences like "I felt in control of the software's situations", "The software is interactive" and "The software is easy to use", and the use of sounds, with the sentences "I like the software's sounds", "The software's sounds are clearly identifiable" and "The software's sounds provide me with information".

3.3 Procedure

Three usability questionnaires were applied. First, the Prototype Interface Evaluation Questionnaire was completed in one 20-minute session, for which the evaluator reproduced each of the sounds and asked the user to provide the sensation or source that he associated with the sound. In addition to this, the tone and speed of the TTS used in the application were tested.

Then, the users worked with ARTAB for a 40-minute session. To do this, a series of tags were placed in a room, in which each one corresponded to a particular object. The users had to navigate the room, locating all of the objects, and informing the facilitator on what they were (Figure 4).

Figure 4. *Users who are blind utilizing ARTAB. A) The user focuses on the object that he wants to ask about, using neck and body movements. B) One member of our research team, in his role as the facilitator, analyzes what the user perceives through the system.*

When the user completes the task of recognizing the tags, he proceeds to respond to the Understandability Questionnaire regarding navigation with the software, taking the amount of time that he deems necessary, with the help of a facilitator.

Finally, the user completed the End-User Questionnaire with the help of a facilitator, who reads the questions and completes the answers given by the user. By considering the results and data obtained from all these evaluations, the software was redesigned to improve the audio interface.

©2010 ICDVRAT; ISBN 978 07049 15022

3.4 Results

From the End-User Questionnaire, we can interpret that the software was highly usable and understandable by blind users (Satisfaction=8.4 points and Control & Use=7.4 points, out of a maximum of 10) (Figure 5). In the "Satisfaction" category, the statements that obtained the highest scores from the users corresponded to "I will use again this software" and "The software is motivating" (9.3 points).

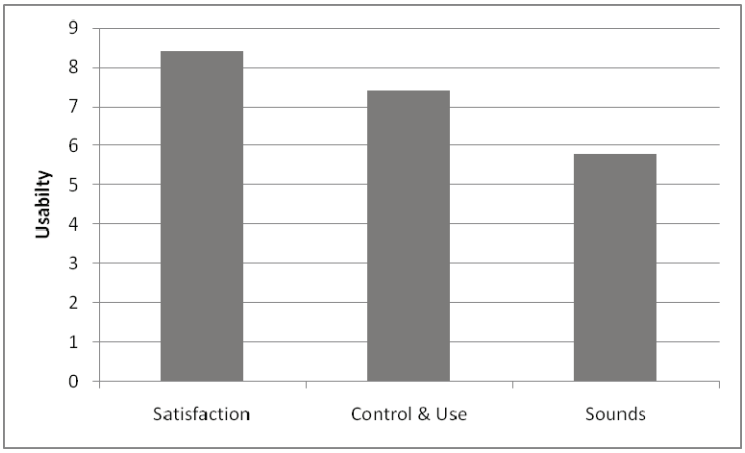


Figure 5. *Results of the End-User Questionnaire.*

The "Control & Use" category obtained a score of 7.4 points due mostly to the fact that the system does not allow for total control by the blind users. That is to say, they could not access the initial configuration menus, nor can they initiate a new navigation, and thus they are limited in that they must be in the company of a sighted person as a facilitator in order to initiate a session. This was reflected in the score obtained by the statement, "I felt in control of the software's situations", which received 6 points of a total of 10, which represents the lowest evaluation in this category. Also in this category, however, the statement that obtained the highest score was "The software is easy to use" (8.7 points). This result denoted the ease of use achieved by ARTAB. The statement with the second highest score was "The software is interactive" with 7.7 points. The "Sounds" category obtained the same results for its two statements, "I like the software's sounds", "The software's sounds are clearly identifiable" (5.3 points). The third statement, "The software's sounds provide me with information" obtained 6.7 points. The problem was that the users who are blind do not note the pitch differences to represent up and down location of the objects.

Regarding the questions on the Understandability Questionnaire, the users recognize that ARTAB allows them to locate objects of interest immediately within the context in which the system is used. They believe that the use of the TTS is adequate, and that this tool can be effective and useful. However, it was noted that in several cases the users did not like the audio feedback used to represent the position of an object that much. They suggested that instead of using a sound that is similar to radar, musical notes should be used in order to indicate the vertical position of the object. The increase or decrease of the volume, as related to the depth, should be more notable, and the navigation bar should be taken better advantage of, in that with 4 buttons the users think that the three remaining buttons might include some additional functions. Together with this, the users that tried the tool felt that ARTAB could be useful and even found other possible applications, such as labeling medicine jars, in which a system with such characteristics could make life easier for them, and make them more independent.

4. PRELIMINARY COGNITIVE EVALUATION

4.1 Sample

For the preliminary cognitive evaluation of ARTAB we considered a sample of 3 users who are blind (totally blind) with ages that ranged between 21 and 30 years old. The sample was made of one woman and two men. None of them had any other neurological deficits.

4.2 Instruments

All the users participated in a test session, for which the material that appears in Figure 6 was created. This material is a representation of what the camera records. The recording is divided into sectors, and subdivided into quadrants. The borders of these quadrants are highlighted, so that the user who is blind is able to distinguish them.

©2010 ICDVRAT; ISBN 978 07049 15022

To obtain quantifiable results with this material, an instrument was designed to measure the level of cognition regarding recognition of the laterality of the sounds. To do this, the evaluation consisted of 3 evaluative criteria: (1) Achieved, if at the time of the evaluation the activity could be performed in its entirety, and independently, for which the user was assigned 2 points; (2) In process, if at the time of the evaluation the user was incapable of performing the activity, being assigned a score of 0 points. The maximum score that could be achieved was 10 points, which is consistent with having correctly located 5 sounds in their corresponding quadrants. This instrument was validated by educators who are experts in visual disorders.

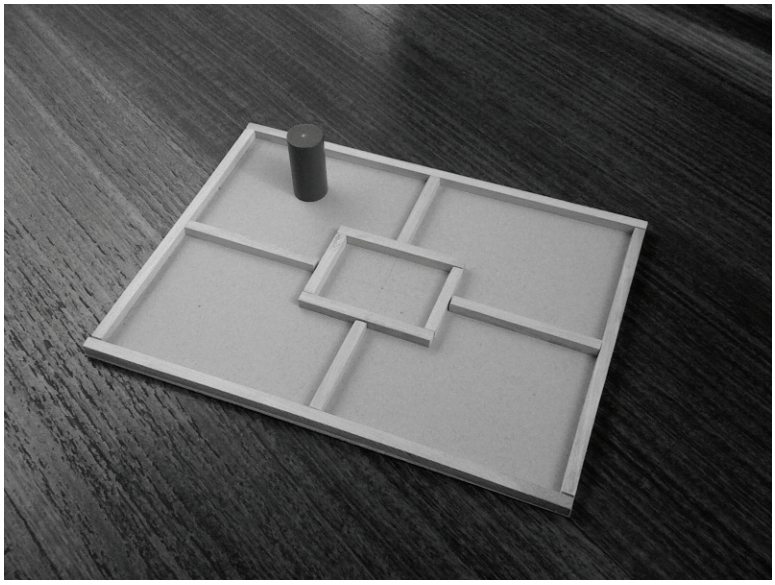


Figure 6. *Test material utilized for ARTAB.*

In addition to using this instrument, non-participant observation was performed in order to detect the way in which the users worked with the ARTAB system while they navigated through an unfamiliar indoor space.

4.3 Procedure

The users were presented with the test material and the division of the sectors was explained. Then, sounds corresponding to the 3D location of the object were played (depth was not used), and the participants had to position the cylinder in the sector that represented the location of the sound in the given quadrant. Five different sounds were played, with differing positions. As the user worked on the material and sounds were played, the facilitator filled in the level of the user's achievement on the specified guideline sheet.

Once the testing had finished, the users navigated using the system by following a route within an indoor space. To do this, they had to navigate from the parking garage on the first floor of the building to the hallway on the second floor. They had to identify doors and the stairway through the use of the proposed system. It is worth noting that the building that they navigated was totally unknown to them.

4.4 Results

The results obtained show that the blind users are able to identify the horizontal sounds represented without any difficulties (9.0 points out of a total of 10 possible points), indicating with precision whether these were located to the right, left or directly in front of them. However, the results obtained regarding identification of the vertical sounds were low (5.0 points). During the test, the users were not able to distinguish if the sound was coming from above or below them. This meant that they were sure of where the object was located horizontally, but not vertically, which translated into frustration due to the fact that the users constantly asked the application about an object that they thought was right in front of them. This brought us to understand that identification of up and down is not a trivial matter for the users, utilizing a system of pitch change in the audio (2 points).

It was observed that the association of the pitch with height was only achieved when the users compared the sound with that which was emitted if the object was correctly centered. This comparison caused the users to spend more time on the vertical alignment than on the horizontal alignment. This implied the provision of assistance in order to indicate when the object was vertically centered, so that the users could then identify if the source was originally above or below them.

©2010 ICDVRAT; ISBN 978 07049 15022

The mental model of the users allowed them to associate horizontality with the use of the left and right channels, and depth with volume; but regarding height, there was no unanimity as far as how to represent it. This dispersal was observed from the evaluation performed, and is key to be able to provide users who are blind with autonomy.

The non-participant observation shows us that the users have problems navigating naturally with the device. This is to say that the ARTAB system is not fast enough in its detection of tags, and thus is not able to identify the objects and transmit the information to users who are blind.

The users are able to control the system with slower movements, so that the camera is able to detect the tags and is thus able to provide the user with correct information. Once the users were able to correctly manage the system, it allowed them to find the correct route adequately. The three participants were able to perform the entire route with total autonomy, using only the proposed system. It was even possible for them to be able to identify the stairway and the landing that is half way up the stairs, without the need for any assistance whatsoever. The level of tags used allowed them to be able to identify navigational routes through the building; however it is not very probable that it would be possible to provide them with specific information on the smaller objects located in the space. This is due to the visual tracking that is provided.

It was also observed during the tests that the younger users were able to use ARTAB more fluidly than the older participants. The younger users, who still had problems using the pitch effect in order to identify the vertical position, were able to overcome this weakness quite well after a few minutes of practice. Although this is positive, we cannot fail to mention the users that did experience difficulties, as this is a point that could mark the difference between choosing to use ARTAB or not.

5. CONCLUSIONS

The main purpose of this research was to design, develop and evaluate ARTAB, a technological assistant for people who are blind that uses Augmented Reality to identify a set of objects in an indoor environment. As a result, we generated audio-based representations that allow a user to determine the position of an object relative to the angle of vision of the video capture device for navigation purposes.

ARTAB is a tool that seeks to assist people who are blind in contexts in which it is necessary to identify certain objects of interest in order to perform a specific navigational activity. It was sought to utilize a representation that would allow users to identify the position of an object relative to themselves through the use of sources of spatialized audio that can be heard through stereo headphones. Due to the fact that the use of the headphones does not allow for the three-dimensional perception of the height and depth from the audio sources, we chose to assign the variations by pitch and volume respectively for the representation of these elements.

According to the usability results from the Understandability Questionnaire, it is clear that the representation on the horizontal axis of a sound source, using the left and right channels respectively, is natural for the users. Even during testing, not one participant had problems aligning the objects on this axis.

One negative point that was detected was the use of the pitch effect. Although in the test activity, the users were told of the significance of this variation, it was quite difficult for them to detect the position of a particular tone. This is to say, the users had to vary the sound manually, moving their head up and down, in order to know the vertical position of the object, represented by a certain audio source.

The users determined that the representation of distance through volume is adequate, granting this aspect a positive affordance. However, it ended up that the variation of this element was too dramatic, in that many participants felt that this aspect of the sound lacked a clear contrast in order to be able to obtain more specific information.

Even taking these negative points of usability into account, the users felt that ARTAB is a useful application that could help them in their daily orientation and mobility tasks. In responding to the End-User Questionnaire, the users even proposed more specific uses for this application, such as for detecting medicines and the contents of containers, thus increasing their autonomy.

Finally, the users that tried ARTAB felt quite enthusiastic about the application, and hope that corrections are made regarding the vertical and depth positioning, in order to be able to use it in environments that they navigate on a daily basis.

©2010 ICDVRAT; ISBN 978 07049 15022

6. FUTURE WORK

It is necessary to continue improving the ARTAB system in light of the usability results obtained. In a new version of the system, the upper and lower parts will be divided into 4 sections each, making for a total of 8 sections. When an object is located within a particular section, it will be represented vertically by a musical note. In this way, ARTAB will represent the vertical position of the objects with a musical octave. We believe that by optimizing the vertical plane, users will be better able to vertically align the objects, generating detection ranges and by using clearly identifiable sounds.

Together with this, the variation of the volume according to the distance must be corrected, adding the function of being able to obtain the approximate distance to an object in meters. This can be achieved by associating the size of the object with its tag, and estimating the distance from the video device based on the dimensions that the object has in the image from which it is viewed.

Once the improvements in the interface have been completed, efforts should be focused on improving the visual tracking system, using other software libraries. This can lead to working directly with computer vision algorithms, transforming the data obtained from an image into information that can be used by our interface.

Currently, we are working on a refactoring process. In particular, the code is being modularized with three main modules: (1) Interface, (2) Application Intelligence, and (3) Modeling the data captured, following an MVC pattern (Gamma, 1995).

Finally, we want to study the option of bringing the system closer to the reality of users who are blind, providing it for use with other hardware platforms to which such users have accesses, such as mobile phones. To do this, it is necessary to consider the processing ability of the phone, to determine if it is possible to perform visual tracking in an optimal way, and to support the energy that is required for the generation of spatialized audio feedback.

Acknowledgements: This report was funded by the Chilean National Fund of Science and Technology, Fondecyt #1090352 and Project CIE-05 Program Center Education PBCT-Conicyt.

7. REFERENCES

P. Angin, B. Bhargava and S. Helal (2010) A Mobile-Cloud Collaborative Traffic Lights Detector for Blind Navigation, Proceedings of the Eleventh International Conference on Mobile Data Management, pp.396-401

R. Azuma (1997) A Survey of Augmented Reality. In Presence: Teleoperators and Virtual Environments 6, 4, pp. 355-385

R. Azuma, Y. Baillot, R. Behringer, S. Feiner, S. Julier, and B. MacIntyre (2001). Recent Advances in Augmented Reality. IEEE Comput. Graph. Appl. 21, 6, 34-47

O. Bimber and R. Raskar (2005). Spatial augmented reality: Merging real and virtual worlds. Wellesley, Mass: A K Peters

Deutsches Institut fu□r Normung. (1998). Benutzer-orientierte Gestaltung interaktiver Systeme: (ISO/DIS 13407 : 1997); deutsche Fassung prEN ISO 13407 : 1997; Entwurf = Human-centered design processes for interactive systems = Processus de conception centrés sur l'individu pour les systèmes interactifs. Berlin: Beuth.

A. Crossan and S.A. Brewster (2006) Two-Handed Navigation in a Haptic Virtual Environment. Proceedings of International Conference on Human Factors in Computing Systems, pp.676-681, Montréal, Québec, (Canada)

E. Gamma (1995). Design patterns: Elements of reusable object-oriented software. Addison-Wesley Professional Computing Series. Reading, Mass: Addison-Wesley.

O. Lahav and D. Mioduser (2008) Haptic-feedback support forcognitive mapping of unknown spaces by people who are blind. International Journal on Human-Computer Studies 66, pp. 23–35

J. Loomis, J. Marston, R. Golledge and R. Klatzky (2005) Personal guidance system for visually impaired people: Comparison of spatial displays for route guidance. Journal of Visual Impairment Blindness 99, 4, pp. 219-232

J. Nielsen (1993) Usability engineering. New York: Academic Press Professional.

M. Sáenz and J. Sánchez (2010) Indoor Orientation and Mobility for Learners Who are Blind. 15th Annual Cybertherapy & CyberPsychology Conference, CyberTherapy 2010, Seoul, Korea, June 13-15, 2010 (accepted, in press)

J. Sánchez (2003) Software Usability for Blind Children Questionnaire (SUBC), Usability evaluation test, University of Chile

J. Sánchez and M. Sáenz (2005) 3D Sound Interactive Environments for Problem Solving. Proceedings of the Seventh International ACM SIGACCESS Conference on Computers and Accessibility, Assets 2005, Baltimore, Maryland, USA, October 9-12, pp. 173-178

J. Sánchez, A. Tadres, A. Pascual-Leone, L. Merabet (2009) Blind Children Navigation through Gaming and Associated Brain Plasticity. Proceedings of the IEEE Virtual Rehabilitation 2009 International Conference, June 29-July 2, 2009, Haifa, Israel, pp. 29-36

J. Sánchez and M. Zúñiga (2006) Evaluating the Interaction of Blind Learners with Audio-Based Virtual Environments. Cybersychology & Behavior, 9, 6, pp. 717

J. Sánchez, H. Flores and N. Baloian (2007) Modeling mobile problem solving applications for the blind from the context of use. International Workshop on Improved Mobile User Experience, IMUX 2007. Toronto, Canada, May 13, 2007

J. Sánchez, M. Sáenz and N. Baloian (2007) Mobile Application Model for the Blind. In C. Stephanidis (Ed.): Universal Access in HCI, Part I, HCII 2007, LNCS 4554, pp. 527–536, 2007. © Springer□Verlag Berlin Heidelberg 2007

J. Sánchez, M. Sáenz and M. Ripoll (2009) Usability of a Multimodal Videogame to Improve Navigation Skills for Blind Children. Proceedings of the Eleventh International ACM SIGACCESS Conference on Computers and Accessibility, Pittsburgh, PA, USA, October 26-28, 2009, pp. 35-42

J. Sodnik, S. Tomazic, R. Grasset, A. Duenser and M. Billinghurst (2006). Spatial sound localization in an augmented reality environment. Proceedings of the 18th Australia conference on Computer-Human Interaction: Design: Activities, Artefacts and Environments. Sydney, Australia, ACM: pp. 111-118

A. Wells (2006) Usability: reconciling theory and practice. In Proceedings of the 24th Annual ACM international Conference on Design of Communication (Myrtle Beach, SC, USA, October 18 - 20, SIGDOC '06. ACM, New York, NY, pp. 99-104

R. Yaagoubi, G. Edwards and T. Badard (2009) Standards and Spatial Data Infrastructures to help the navigation of blind pedestrian in urban areas. Urban and Regional Data Management - Krek, Rumor, Zlatanova & Fendel (eds), Taylor & Francis Group, London, pp. 139 - 150

J. Zhang, S. Ong and A. Nee (2009) Design and development of a navigation assistance system for visually impaired individuals. In Proceedings of the 3rd International Convention on Rehabilitation Engineering Assistive Technology, April 22-26, Singapore, pp. 1-4

©2010 ICDVRAT; ISBN 978 07049 15022

PiTaSu: a wearable interface for assisting senior citizens with memory problems

T Kuroda[1], G Yamamoto[2], D Yoshitake[3], S Hickey[4], J Hyry[5], K Chihara[6], P Pulli[7]

[1]Department of Medical Informatics, Kyoto University Hospital,
54 Kawahara-cho, Sakyo-ku, Kyoto, JAPAN

[2]Graduate School of Natural Science and Technology, Okayama University,
3-1-1 Tsushima-naka, Kita-ku, Okayama, JAPAN

[3,6]Graduate School of Information Science, Nara Institute of Science and Technology,
89 16-5 Takayama, Ikoma, Nara, JAPAN

[4,5,7]Department of Information Processing Science, University of Oulu,
P.O. Box 3000, 90014, Oulu, FINLAND

[1]*tomo@kuhp.kyoto-u.ac.jp*, [2]*goshiro@sys.okayama-u.ac.jp*, [3]*daisuke-yo@is.naist.jp*,
[4]*seamus.hickey@oulu.fi*, [5]*jaakko.hyry@oulu.fi*, [6]*chihara@is.naist.jp*, [7]*petri.pulli@oulu.fi*
[1]*kuroda.kuhp.kyoto-u.ac.jp,* [2]*goshiro.jp,* [3,6]*chihara.aist-nara.ac.jp,* [4,5,7]*psesc.oulu.fi*

ABSTRACT

Little research has been carried out on specialized wearable user interfaced designs to assist memory impaired senior citizens. This paper proposes and implements PiTaSu (Picture based Tapping on wall Surfaces) to realize direct user interface system to offer visual feedback and tactile feedback. PiTaSu is based on a pictorial based Augmented and Alternative Communication (AAC) system. PiTaSu consists of a body-worn or shoulder-attached mobile projector, a camera and an accelerometer wrist band. The projector shows information that will help assist the memory impaired senior citizen in their daily task. The camera and the accelerometer detect a tapping position and tapping trigger. Experimental results have demonstrated that a senior citizen can use PiTaSu without learning special skills, and the projection based user interface has potential. Therefore, PiTaSu can assist memory-impaired senior citizens as a daily task reminder.

1. INTRODUCTION

Memory related illnesses are a common problem with senior citizens. A number of industrialized countries have a rapidly aging population, and consequently there is a corresponding rise in age related memory illness. This paper describes one part of a ubiquitous information support for senior citizens with memory problem that can be realized through an intuitive wearable interface. The realization of the support acts as a key for providing comfortable living for both supported and supporting people. The SESC (Smart Living Environment for Senior Citizens; Metso, 2009) project has been conducted based on such an idea.

Most senior citizens suffering from memory problems can tell their intentions though they are weak in their acknowledgement of time events. If they can access the information they need, they can have the potential to live independently. To realize this support using computer power, an easy-to-use interface is necessary and important for the senior citizens. Currently, health care professionals use Augmentative and Alternative Communication (AAC) to help people with memory problems in their daily activities (Tetzchner, 1992). There are numerous AAC methods. The representation system used in AAC include gestures, hand signal, photographs, pictures, line drawings, words and letters, but also different ways of managing computer aided communication tools. In this paper, a pictorial bases system is used with image-printed tags or pictures that can be placed on walls or places and these are shown to other people. AAC method that focus on picture communications using these tags or pictures are a common means to support memory-impaired patients perform daily tasks. The number of tags or pictures changes according to the complexly of the communication. It is difficult to make a deep conversation using physical real object as tags or pictures without mobility.

©2010 ICDVRAT; ISBN 978 07049 15022

This paper focuses on a user interface using a projection-based wearable system for assisting senior citizens with memory problems to support one type of pictorial based AAC system. Using mobile projectors would turn physical surfaces into information displays, thus providing ubiquitous information in a daily living environment. There are three main advantages for using projectors compared with flat panel monitors; Firstly, projectors can achieve a wide display originating from very small devices. Secondly they're able to project information on many physical, flat surfaces. Third, they provide a greater mobility that move with the person rather than been confined to fix contexts. These elements have potential for personal use applications added in mobile or wearable computing. There are some studies for developing a novel user interface on PROCAMS (projector camera system). The systems have one feature in common, which is to attach physical markers on a target surface for achieving stable projection of virtual images. The feature has a problem that a projected area which provides stable enough images are limited to surfaces that have attached markers.

In this paper, a wearable PROCAMS, PiTaSu (Picture based Tapping on wall Surfaces), with a novel user interface is proposed. The system accepts tapping action onto wall surfaces as an input, as shown in Figure 1. It is thought that tap action is suitable as an interactive input interface because it is operation that everyone is able to do easily. A contextual background system provides relevant information based on users action history from a database, but this part of the system is out of the scope of this paper. Since users tap real surfaces for physical input, they can get a sense of haptic feedback when tapping a wall. In this proposed system, projected images aren't corrected with markers. We think that users could recognize contents of a bit distorted images, or they can change the orientation of the projector to correct that.

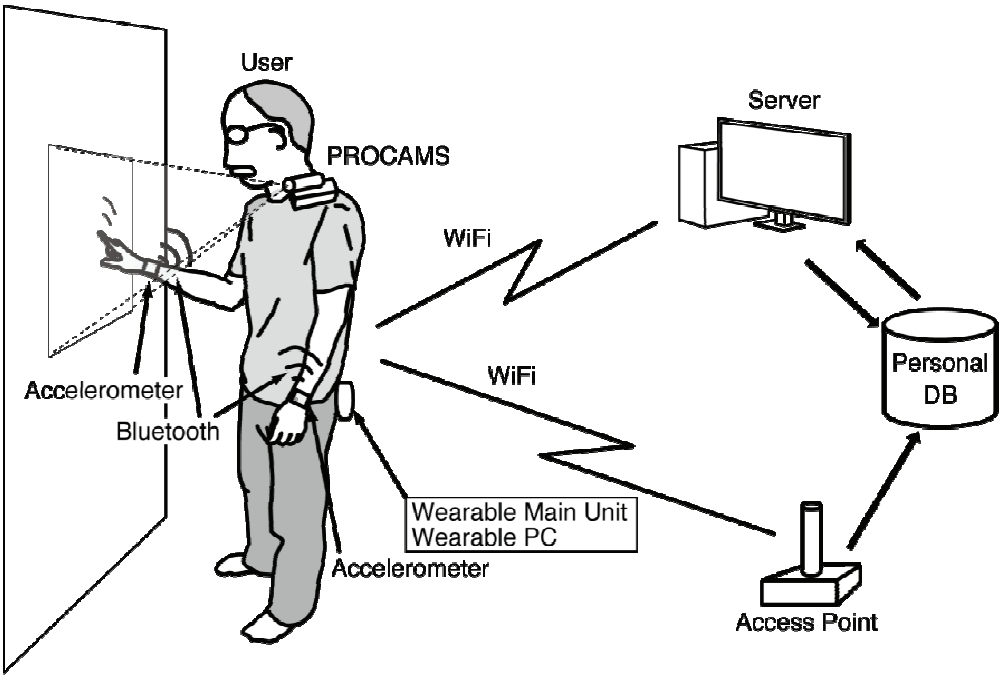


Figure 1. *Conceptual overview of proposed projection based wearable system. The wearable system that consists of PROCAMS and accelerometer and computer connects with server and access point via WiFi.*

2. A WEARABLE INTERFACE IN SMART LIVING ENVIRONMENT

Senior citizens have certain needs that designers normally don't have to take into account when designing new systems as the primary target groups often consist of a younger user base. Instead of making elderly people understand deep and often complex structures of varying mobile phone user interfaces, and the meaning of arbitrary icons and illogical functionalities created from bad design choices, the aim should be about simplifying things and taking advantage of the skills everyone learns when they grow up. Learning new things becomes slower with age (Kelley, 1995) and senior citizen also have a tendency to reject new technological devices (Bjørnerby, 1999), even though they could offer benefits to their lives. Advantages of PiTaSu design choices, which is the proposal system in this paper, is that the user is able to use it without learning new control methods, as opposed to hand marker based gesture navigation with colour markers added to fingers (Mistry, 2009) or using IR-led fingertip attachment (Karitsuka, 2003). Research on the

©2010 ICDVRAT; ISBN 978 07049 15022

wearable user interface needs focuses on Alzheimer's disease and its close, treatable variants. This is because a vast amount of different memory related illnesses require specific, customized designs. Other illnesses, such as semantic dementia, can present symptoms that are difficult or infeasible to assist with different technological devices. Choosing Alzheimer's is feasible because of the nature of the illnesses symptoms, such as episodic memory functioning problems (Dubois, 2007) and its frequency among the elderly. Based on discussions with medical doctors and a neuropsychologist, it can be also considered feasible for these technological aids to improve the lives of the patients. It is also possible that they assist in slowing down the rate of brain functions deterioration via memory supporting effects, environment, and with services originating both inside and outside of the living environment.

The user interface design used in this work is based on a path structured approach as shown in Figure 2 (Pitkanen, 2010). The language reads from left to right, with the left most pane featuring the key needs of the user, e.g. 'I want'. This first pane can be filled with alternatives which are partly based on the senior citizens contextual situation. Once a picture is selected, e.g. I want, a second list of options is opened in the 2nd pane, such as 'to go' or 'to call'. When one of these options is selected, the 3rd pane is opened with a further list of options, and so on. The selected options which make up the activity are shown at the top of the UI, in this case 'I want to call Anna'. The language also works in the reverse, with health care professionals creating a message for the senior citizen which can be linked to a context. When the senior citizen is in that context, the message can be shown to them pictorially.

The main interactions with the system are done with two separate user interfaces - one for the medical personnel or a trusted person, and one for senior citizen user. For example the doctor can add appointments to senior citizens calendar via a computer interface or they can monitor current health or check medical history of the user. A trusted family member can check if senior citizens calendar entries are acceptable and do not have any inconsistencies. Graphical user interface for the senior citizen is built up of different modules as shown in Figure 2 left. The communication module has tools for video, phone calls and messaging. The guidance module is a subset of two areas, home and outdoors, and handles information of routes, locations and instructions for tasks. The home module is designed for home specific tasks, such as cooking or reminders. Scheduling module is split for multiple users as data acquisition and entry is possible from different terminals. The emergency module handles direct requests from the user or via automatic recognition and forwards these to the appropriate party.

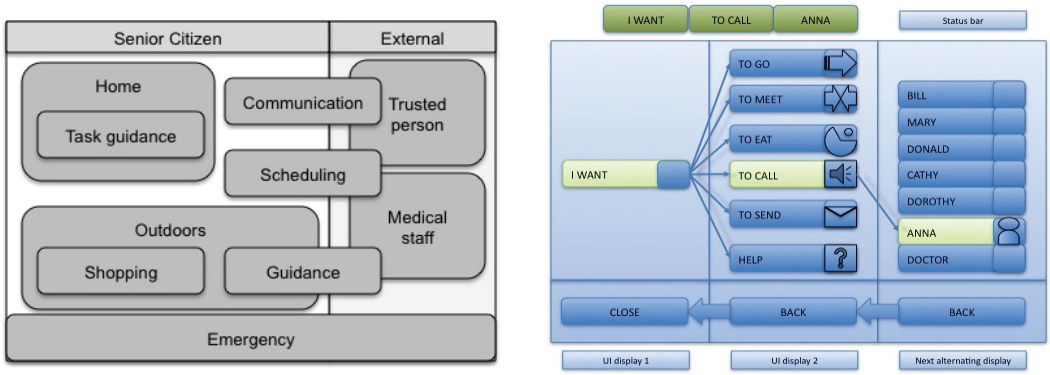


Figure 2. *Left: Modularity overview. Right: Senior citizens path-structured user interaction UI concept example.*

3. PiTaSu: SYSTEM OVERVIEW

This paper shows a proposal system that combines an accelerometer with a projector and camera, as shown in Figure 1. Using this wearable PROCAMS, which is called PiTaSu (Picture based Tapping on wall Surfaces), a novel user interface is suggested. A user takes on this projector-camera unit around on their own shoulder or chest, and wears an accelerometer on their own wrist. It offers and intuitive interface that accepts tapping images on wall surfaces as input action. To realise this proposed tapping input interface, PiTaSu should detect tapping trigger and a position of a finger-tip on the wall surface projected with light. In this section, the method of processing to detect this information is described.

3.1 A Process to detect tapping

The following describes how to detect direct tap input in PiTaSu system. The method is divided into four steps: detecting tapping trigger, calculating homography matrix, recognizing the hand area and estimating the finger-tip position, as shown in Figure 3. It explains each steps separately for 3.2 – 3.5 section.

©2010 ICDVRAT; ISBN 978 07049 15022

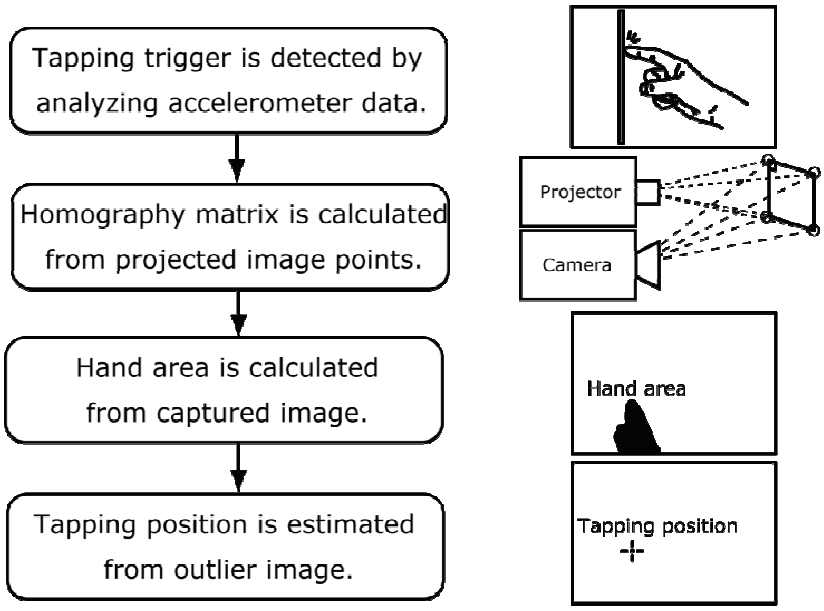


Figure 3. *Flow chart of processing to detect tapping and pointing finger-tip position. This process consists of four steps; detecting tap-trigger, calculation of homography, recognition of the hand area, and estimation of the finger-tip position.*

3.2 Detecting Tap-Trigger

The vibration of a user wrist when the user taps on surfaces can be acquired because the accelerometer is worn at the user wrist. Tapping trigger is detected from a sequence of acquired accelerometer data on user's wrist through a FFT. When a spectrum value exceeds a certain threshold value in a high frequency area, the action in that time is recognized as tapping. This system uses simple processing though it is necessary to use a method such as PCA to achieve recognition with high accuracy.

3.3 Calculation of Homography Matrix

It is necessary for detecting the tapping position on a target surface to calculate the homography matrix. The homography is calculated from four projected points on the surface. Some input hand motions, however, intercept one of these points. Therefore PiTaSu estimates a point from the relationship among three projected points on a wall surface. Then, a homography is calculated from using these four points.

3.4 Recognition of the Hand Area

A ray transfer model (Grossberg, 2004) could be defined for PROCAMS where the brightness ray from the projector is reflected on a target surface and captured. When it's assumed that the ambient light source and ratio of surface reflection are equal on the whole the projection area, we can define transfer ray and ratio of reflection as a simple equation in each case (RGB). The equation of transfer ray I_c is as follow,

$$I_c = R(I_p + I_0) \tag{1}$$

$$= RI_p + RI_0 \tag{2}$$

where I_0 is an environment light source, R is a ratio of a wall surface reflection, I_p is projection ray from the projector. In addition the environment light source and the ratio of the wall surface reflection are unknown variables. When it is assumed that the environment light source and the ratio of a wall surface reflection are equal on all of the projection area, then, we can define that RI_0 as a ray of 0 for projector brightness and substitute $I_{cBK} = RI_0$ for Equation 2.

$$R = \frac{I_c - I_{cBK}}{I_p} \tag{3}$$

The ray from projector has three values of RGB light source. Equation 2 and 3 are operated as follows,

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

$$I_{c*} = RI_p + I_{cBK} \tag{4}$$

$$R_* = \frac{I_{c*} - I_{cBK}}{I_{p*}} \tag{5}$$

where * in Equation 4 and 5 means a value of RGB light sources.

If we assume that I_{cR}, I_{cG}, I_{cB} and I_{cBK} are reflections from a wall surface, then we can calculate the transfer function of the PROCAMS model. Using the calculated transfer function of the PROCAMS model, the brightness of reflection on the surface can be estimated. The system compares this estimated brightness and a captured brightness by camera, to judge the existence of an outlier. Only some projection rays are used to calculate because comparing all of the projection rays increases computational complexity.

Figure 4 (a) is one of outlier image. This image has noise from shadow and defocus. To recognize the hand area, outlier image is processed with labeling operation and the result is shown in Figure 4 (b). When it is assumed that an input action must enter the projection area, the hand area has captured-screen edge. Therefore, the area that has not captured-screen edge, is considered noise. In addition, the largest area that has captured-screen edge is recognized as a hand area.

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

Figure 4. *Detect finger-tip pointing position from outlier image. (a) one of outliner images, (b) the result of labelling operation, (c) the outlier's edge, (d) finger-tip pointing position.*

3.5 Estimation of the Finger-tip Position

The recognized hand area image is processed with edge detection. Then, a distance from image-screen edge is calculated along the hand area outline, as shown in Figure 4 (c). Furthest point on the outline is estimated to finger-tip direction, as shown in Figure 4 (d). Finally that same point is defined as finger tips position.

4. EVALUATION EXPERIMENT

The prototype system is developed and the usability of the tapping input interface is evaluated through user testing with elderly people. The performance evaluation was also verified to confirm an input response time, resolution and available environment.

4.1 Prototype System Configuration

The prototype system consists of a projector (3M™ Micro Professional Projector MPro110, SVGA), a camera (Logitech QuickCam Vision Pro, 960x720 pixels), an accelerometer (ATR-Promotions WAA-006), and a computer (Lenovo ThinkPad X61, 271g), whose weight is 271g excluding the computer. Figure 5 shows an appearance of the prototype system and a user interface design on the system. At first, the camera is calibrated using Zhang's method (Zhang, 2000) to get undistorted images. The projection image has a colour marker at left-upper side to detect a hand area. The colour marker consists of 4 colours; Red (255, 0, 0), Green (0, 255, 0), Blue (0, 0, 255) and Black (0, 0, 0) in RGB colour space. Using this colour marker, the system calculates RGB colour transformation matrices in each frame. Then, four points at corners of a projection image are used to calculate a homography matrix.

©2010 ICDVRAT; ISBN 978 07049 15022

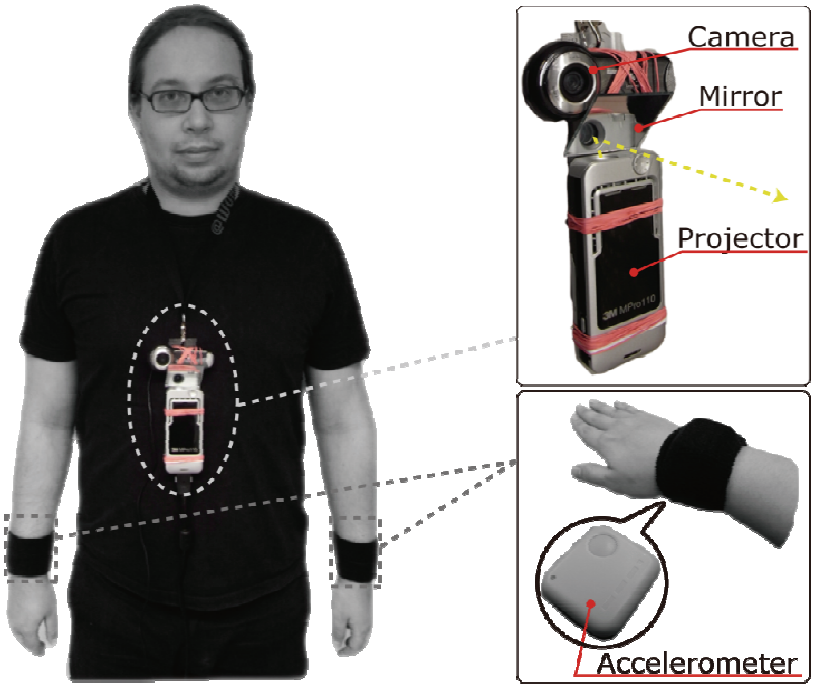


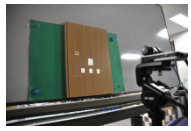
Figure 5. *Prototype system overview. A projector-camera unit is hanging on user's neck. An accelerometer is worn on user's wrist by wristband.*

4.2 Evaluation of System Availability

To confirm available environments of the system, the projection experiment was executed for some surfaces. In this experiment, five materials were chosen as projection monotone wall surface. These surfaces properties (material and Lab colour space) are as follows; drawing red paper (56.26, 61.98, 29.59), drawing green paper (97.75, 3.86, 89.56), drawing yellow paper (61.48, -38.4, 16.98), mat surface wood (112.4, 8.03, 17.74), and shiny surface wood (73.88, 13.06, 43.08). These colour properties are measured by a chroma meter (KONICA MINOLTA CS200).

A projection and a tapping input that were the fundamental system operations were done to each material surface. As the results, shown in Table 1, there were problems for drawing green paper and mat surface wood although the system operated normally for other materials. The result for drawing green paper shows that the acquisition radiance value of the colour marker was low, and the reflection from the wall was judged as a hand area. Mat surface wood interferes in the distinction between the wall and the hand area.

Table 1. *Results of evaluating system availability for five materials.*

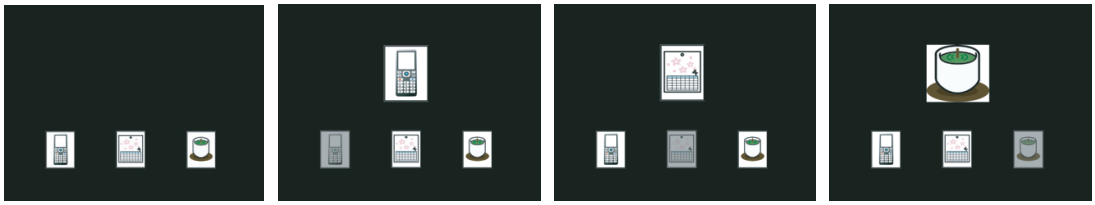
Appearance of Material	Drawing red paper	Drawing green paper	Drawing yellow paper	Mat surface wood	 Shiny surface wood
Chroma meter value in Lab colour space	(56.26, 61.98, 29.59)	(61.48, -38.4, 16.98)	(95.75, 3.86, 89.59)	(112.4, 8.03, 17.74)	(73.88, 13.06, 43.08)
System availability	Available	Not available	Available	Not available	Available

4.3 Evaluating Reactions

In this usability test, a senior citizen subject is given a simple task, which is to select the projected images. The senior citizen has no previous experience or training in the use of the system. The senior citizen subject is 84 year-old man and never tested dementia level. The subject cannot raise his arms much above shoulder height because he has shoulders slightly sore. Figure 6 shows the user interface design of the experiment.

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

There are three selectable pictures in the bottom of the screen, and the user taps one of these pictures. Then, the system presents at the top area of the screen the tap-selected picture. The experiment consists of two steps. The first step is to confirm that the projected images allow the subject to tap them like a button without previous training. The second step is to confirm that the senior subject could use the interface and what issues they had in using the interface. After the tapping tasks, the subject answers three questions.



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

Figure 6. *User interface configuration. (a) Initial screen, there are three selectable pictures in the bottom, (b, c, d) The top bigger pictures is presented according to user selection.*

Through an active observation of the senior citizen subject in step 1, it can be seen that he can touch projected images as the input action without an explanation on how to use it. After training, the tap task of 40 trials is given to the subject for calculating tap recognition rate. In the result, there were 22 successes (55%), the false detection of 9 times, and 9 no detection. The following are answers to the questionnaire.

- *Does wearing the device feel strange or uncomfortable to you?: Not really. The device is not heavy and I can imagine wearing it throughout the day. The device does feel a bit loose, though. It should be more stable. The picture displayed swings around the wall as the device moves.*
- *When inputting with the device, do you feel any strange or difficult points?: Not really, but I would imagine that if I will use the system whole day, my fingertips might become sore. I thought that maybe I will need some kind of protection for may fingertips.*
- *Anything else about the system?: All the icons did not look like what they supposedly were representing. Teacup looked like a candle and the cellphone looked like a door. The calendar icon, however was easily recognized.*

5. DISCUSSION

The performance of this system and its user interface was confirmed through two experiments. In this section, the usability of the system and the effectiveness of the user interface for senior citizens are discussed by the experimental results.

The first experiment that was to confirm system availability, it was clarified that the system had weak points according to the surface condition. On the surface of green drawing paper, the system cannot process the necessary calculations for projection because the radiance value of the projected markers cannot be observed through the camera. It is thought that this material is a dark shade, and consequently it has the characteristic in which the projector light cannot be strongly reflected. One solution is to have much stronger projector light. Because a device exists that projects a much brighter light compared with the projector used in this the prototype system, the possibility that this problem can be solved is high today. On the other hand, it is one of the factors which can limit system available environment because there are generally a lot of surfaces (especially wall) in an interior of a house, e.g. like white. On the surface of mat surface wood, the system cannot distinguish the presence of a hand, as the reflection surface property of the mat surface wood is similar to one of the hand. Therefore, wooden products in the house cannot be target objects to be projected. These problems should be considered with the influence by ambient light, and cannot declare a quality of this system from this experiment result categorically. A new prototype system might be made with a bright light projector and an experiment that includes ambient light as one of its components is necessary in the future.

The second experiment in which the senior citizen subject had used the system has been set to confirm a usability of a proposal direct manipulation interface based on projection. The result of the intuitive tapping task shows that the projected icons have an affordance to let the user tap onto it naturally. A point where this training is unnecessary becomes a major plus when it is assumed that senior citizens use the proposal system

©2010 ICDVRAT; ISBN 978 07049 15022

in smart living environment. Therefore, it is expected that this projection-based wearable system can offer senior citizens AAC communications anytime and anywhere. After knowing the usage, the usability of the system for the senior citizens was evaluated by observation of the subject during the tapping recognition task and by a follow up questionnaire. The recognition rate decreased by up to 55% in two causes. One is the process where the tap action is extracted from a sequence of the accelerometer data. In the prototype system, it is defined that a spectrum value of a high frequency area rises to a particular threshold. It is necessary to analyse the tap action by the principal component analysis etc. to raise the tap recognition rate. Another cause is in the process of estimating a finger-tip position. The estimation method depending on a distance edge to finger-tip has the possibility of causing a gap between a true tapping position and an estimated tapping position. The gap is sometimes caused easily when two fingers or more are used to do the tapping action. To compensate for this, new solution methods will presume a tapping finger-tip and expanding the tap reaction area.

In the following, the answer to the questionnaire is discussed. From the first answer, it was shown that this system did not give a user a feeling of discomfort when wearing it. This is a great result for a wearable system. However, the subject pointed out that there is a fault that a projected image swings according to a movement of PROCAMS when it is worn about the neck. As this solution, it will be possible to fix the PROCAMS to the body so that the PROCAMS should not swing because an approach from software is difficult. The second answer shows that a user was able to use this system intuitively. It is thought that one of the reasons why subject answer about the pain of his finger-tip might be repeating strong taps because of the low rate of the tap recognition. If a user accepts attaching something to their finger-tip, better accuracy of the tap recognition is possible. It is necessary to contemplate this wearing on a finger-tip in the future. For the third question, the subject answered the visibility of icons. As the focus length of the projector is not dynamically changeable, an image out of focus is projected onto a wall surface according to a distance. The visibility of the projected images decreases by out of focus. In AAC communications, it is fatal not to be able to distinguish the projected images. Therefore, it is necessary to present the guideline for making icons on this system to keep the visibility.

Some problems were found aiming at a development in the future as discussed by the above. Basically, the user interface that became important in smart living environment through this study was able to be made wearable.

6. CONCLUSIONS

PiTaSu has provided an intuitive tapping interface on a projection-base wearable system. This prototype system could detect finger-tip position on the target surface by comparing estimated reflection with the captured reflection. Using this system might offer users with memory problem an easier to use system with its haptic and visual feedback when user taps the projected images in the ubiquitous information environment. In smart living environment offered by P-SESC, the proposal system becomes the most important interface on the user side.

In the experiment results, the available environment and the effectiveness of the system were examined. The system was unavailable on surfaces which reflects projector light weakly and on surfaces which has a texture plane near skin-colour though it is possible to use on some surfaces. There is no major problem for the reflection of the projector light because the surface of a lot of walls in the house is like white colour. As it is difficult to distinguish the surface of matted woods from a hand, it is necessary to be careful in using the system and finding an appropriate image processing technique becomes one of future works. Through the user testing, it is shown that PiTaSu helps to assist memory-impaired senior citizens without learning special skills. Additionally, the senior citizens subject had no feeling of discomfort by using a wearable system, and it was confirmed that he tapped onto the icons naturally. If the processing algorithm of the accelerometer data is improved, the accuracy improvement is expected though the success rate of the input operation was 55%.

Future work will include a more comprehensive user testing planning for the senior citizens with memory problem. This would then help to determine the viability of establishing this interface technology in future smart living environments.

Acknowledgements: This work has been partly founded by the Academy of Finland and JSPS, Japan under Smart Living Environment for Senior Citizen research projects (P-SESC).

©2010 ICDVRAT; ISBN 978 07049 15022

7. REFERENCES

T Amano and H Kato (2008), Appearance enhancement using a projector-camera feedback system, *Proc. of* , **22**, *11*, pp. 1330–1334.

S Bjørnerby, P Topo, and T Holthe (1999), *Technology, Ethics and Dementia: a guidebook on how to apply technology in dementia care*, Norwegian Centre for Dementia Research.

B Dubois, H H Feldman, C Jacova, S T DeKosky, P B Gateau, J Cummings, A Delacourte, D Galasko, S Gauthier, G Jicha, K Meguro, J O'Brien, F Pasquier, P Robert, M Rossor, S Salloway, Y Stern, P J Visser, and P Scheltens (2007), Research criteria for the diagnosis of Alzheimer's desease: revising the NINCDS-ADRDA criteria, *The Lancet Neurology*, **6**, *8*, pp. 734–746.

M Grossberg, H Peri, S Nayar, and P Belhumeur (2004), Making one object look like another: Controlling appearance using a projector-camera system, *Proc. IEEE Conf. Computer Vision and Pattern Recognition*, **1**, pp. 452–459.

T Karitsuka and K Sato (2003), A wearable mixed reality with an on-board projector, *Proc. IEEE and ACM Intl. Symp. on Mixed and Augmented Reality*, pp. 321.

C L Kelly and N Charness (1995), Issues in training older adults to use computers, *Behaviour & Information Technology*, **14**, *2*, pp. 107–120.

A Metso, P Pulli, S Hickey, and X Zheng (2009), Ubiquitous services for senior citizens – Living process detection and middleware, *Proc. Intl. Conf. Computer and Information Science*, pp. 846–851.

P Mistry, P Maes, and L Chang (2009), WUW – Wear Ur World – A wearable gestual interface, *the CHI '09 extended abstracts on Human factors in computing systems*, Boston, pp. 4111–4116.

A Pitkanen and S Hichey (2010), Implementation of model-based user interfaces for pictorial communication systems using UsiXML and Flex, UsiXML-EICS workshop of ACM SIGCHI Symp. on Engineering Interactive Computing Systems, Berlin.

S von Tetzchner and H Martinsen (1992), Introduction to symbolic and augmentative communication, Whurr Publishers, London.

Z Zhang (2000), A flexible new technique for camera calibration, *IEEE Trans. on Pattern Analysis and Machine Intelligence*, **22**, *11*, pp. 1330–1334.

©2010 ICDVRAT; ISBN 978 07049 15022

Designing an ecological virtual task in the context of executive functions: a preliminary study

X Cao[1], A-S Douguet[2], P Fuchs[3], E Klinger[4]

[1,4]Arts et Métiers Paristech - LAMPA, Angers-Laval, FRANCE

[2]Kerpape Rehabilitation Center, Ploemeur, FRANCE

[3]MINES ParisTech, Paris, FRANCE

[1]*cao.elhit@orange.fr*, [2]*asdouguet@kerpape.mutualite56.fr*, [3]*philippe.fuchs@ensmp.fr*, [4]*evelyne.klinger@ensam.eu*

ABSTRACT

Brain damage is a major cause of disability that often leads to deficits in executive functions with dramatic consequences on activities of daily living. While rehabilitation approaches of the dysexecutive syndrome are still limited, virtual reality has shown its potential to propose innovative intervention strategies based on ecologically valid functional tasks. The Therapeutic Virtual Kitchen (TVK) was designed as an assessment tool to help therapists and their patients with brain injury. In the TVK, some ecological virtual tasks may be configured by the therapists for patients' assessment and rehabilitation. The purpose of this paper is to validate the feasibility of the TVK with healthy subjects and patients with brain injury in Kerpape Rehabilitation Center.

1. INTRODUCTION

Executive functions (EF) are defined as higher-order functions that are needed to perform organized goal directed behaviors. EF include the capacity for initiative, formulating goals, planning, organization, reasoning, control, audit, abstract thinking and self-awareness (Godefroy, 2003). Deficits in EF may be the consequence of brain damage such as stroke or Traumatic Brain Injury (TBI). EF alteration, also called the dysexecutive syndrome, disrupts Instrumental Activities of Daily Living (IADL) (e.g. meal preparation), prevents return to social and professional life, and finally leads to loss of autonomy (Fortin et al, 2003). According to literature (Katz and Hartman-Maeir, 2005; Pradat-Diehl et al, 2006), it is recommended to use IADL to assess and train EF. But due to both time and economic constraints, therapists do not have enough opportunities to propose such ecological approaches to their patients. Functional virtual environments seem to be a possible way to overcome these limitations. During the last decade, a wide range of studies has shown the feasibility of using Virtual Reality (VR) for cognitive care (Rizzo et al, 2004; Rose et al, 2005; Klinger et al, 2006). VR has been implemented for assessing and training various cognitive deficits in: Memory (Brooks et al, 2004), Attention (Rizzo et al, 2006) and executive functions (Klinger et al, 2006). In particular, researchers have investigated the potential of virtual kitchens to assess and train patients with dysexecutive syndrome. Davies et al. described the issues encountered in the development of a rehabilitation VR based kitchen work, e. g. the means of interaction with the 3D objects or the way to provide helpful cues (Davies et al, 2002). Zhang et al. proposed to patients after TBI to complete meal preparation both in a VR kitchen and a real kitchen twice over a 3-week period (Zhang et al, 2003). They established the adequate reliability and validity of the VR system as an assessment method in persons after TBI. In their single case study, Fidopiastis et al. trained a participant with working memory impairment in breakfast preparation in a mixed reality. The system included real and virtual objects as well as environmental conditions (Fidopiastis et al, 2006). They underline transfer of learning from the mixed reality environment to the home environment.

In the framework of our collaboration with Kerpape Rehabilitation Center, we designed the Therapeutic Virtual Kitchen (TVK) in which we implemented an adaptable virtual Instrumental Activity of Daily Living (vIADL) (Klinger et al, 2009). The TVK allows the therapist to adapt virtual kitchen tasks to patient capacities, and allows the patient to experience graduated tasks. The goal of this study is to validate the feasibility of the TVK with healthy subjects and patients with brain injury (stroke or TBI). The final purpose of our current work is to investigate how capacities learned in a virtual task can be generalized to the same task in the real world.

©2010 ICDVRAT; ISBN 978 07049 15022

2. INSTRUMENTATION

2.1 The TVK

After having studied the habits and needs of Kerpape therapists, we designed the TVK that is graphically very close to the Kerpape Center kitchen (Klinger et al, 2009) (Figure 1). Its various functionalities include behaviors of all the 3D objects that are required in meal preparation or follow-up of all the activity of the participant. Real sounds are provided according to the activated 3D objects, in order to increase the feeling of immersion within the virtual kitchen. According to the configuration of the task, therapist can provide help to the participant via visual or auditory cues by pressing keyboard keys (F1: a voice, F2: a message on screen, F3: a red arrow to indicate the object to interact with). Mouse visual cues are provided to facilitate the understanding of the interaction opportunities, like the modification of the mouse cursor according to user action (take, pour, activate, connect) (Figure 2). To carry an item from one place to another one, the item is sticked on the mouse after its selection. In our objective of low cost devices use, the virtual task is displayed on a computer screen while the participants navigate and interact with the 3D objects using respectively the keyboard arrows and the mouse while performing the task. The TVK offers the therapist various possibilities to individualize the task, to adapt it to the capacities of the participant (e.g., number of cups of coffee to prepare), to graduate the difficulty by changing the initial position of the required items or to reach therapeutic purposes (assessment or rehabilitation).

Three softwares were used to create the TVK: 1) The *Java* platform for creating the therapist's interface; 2) *Autodesk 3DS Max* (*www.autodesk.com*) for modeling the 3D kitchen; 3) *3DVIA Virtools* (*www.3ds.com/products/3dvia/3dvia-virtools)* for creating the scenario and the tasks in the virtual kitchen.

Figure 1. *Kerpape real kitchen (left) and the TVK (right).*

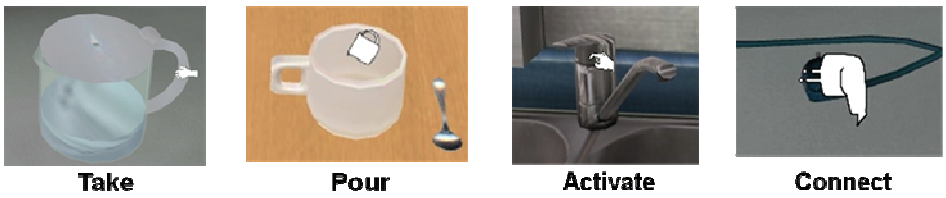


Figure 2. *Four mouse visual cues*

2.2 Virtual Activities of Daily Living (vADL)

The final purpose of the TVK is to engage participants in various vADL, like the preparation of a coffee, a soup or a meal. In order to reach that purpose the TVK software proposes two types of tasks: "primary" tasks and "complex" tasks. Primary tasks (PT) were designed to insure the familiarization of the participant to the system and tools, but also to provide simple tasks which can be proposed before engaging the patient in the complex task. An example of primary task is "take a glass and put it on the table". A limited number of actions of the participant are necessary to achieve a primary task. Complex tasks (CT) are vIADL such as "coffee preparation". They require both planning of steps and spatio-temporal organization.

The CT task that we developed in the TVK is the preparation of a coffee. Graduation of the task is ensured by various parameters, like: 1) number of cups to prepare (from one to six), for counting requirements; 2) time's constraint, for time organization and stress induction; and 3) position of the required items (easy: all are ready at the right place; medium: all are on the table; hard: necessity to fetch all the items in the cupboards or in the drawers), for change of difficulty. The number of steps of the task depends on items positions and nature of the coffee (easy: 12 steps; medium: 14 steps; and hard: 16 steps).

©2010 ICDVRAT; ISBN 978 07049 15022

2.3 The virtual assessment grid

Kerpape therapists use an assessment grid related to the coffee preparation task that was locally developed (Jouadé, 2003). It includes 16 types of errors: 6 actions errors (e.g., action omission) and 10 behavior errors (e.g., difficulty in decision making).

A part of the Kerpape assessment grid was computerized. Actually, the TVK can record 10 types of errors including of 6 actions errors (actions omissions, actions not completed, perseveration, sequence errors, actions additions and control errors) and 4 behavior errors (error recognition, difficulty in decision making, dependence, no use of therapist's help). The six actions errors can be automatically interpreted and recorded by the system in the virtual assessment grid. The four behavior errors must to be interpreted by the therapist and then can be recorded in the same grid after the therapist presses a keyboard key. If the patient needs instructions recall, he can press the SPACE key, and then the system records a dependence error.

We did not take into account the six other behavior errors of the real assessment grid (e.g., not appropriate behavior) because their interpretation by the therapists is still too subjective.

3. EXPERIMENTS

The goal of the two experiments we carried out was to explore the functioning of the TVK and the feasibility of the complex coffee task with healthy subjects (Experiment1) and patients with brain injury (Experiment2).

3.1 Participants

Participants of Experiment1 were 13 Kerpape Center employees (control group) (11 F, 2 M, mean age: 39 ± 6 years). They were recruited among the center staff: 2 neuropsychologists, 4 occupational therapists, 1 clinician, 2 physiotherapists, 1 orthoptist, and 3 center employees.

Participants of Experiment2 were selected among Kerpape patients with brain injury, according to 9 inclusion criteria (e.g., score of BDVO (Battery of visual decision of objects) > 67/76) and 10 exclusion criteria (e.g., Pregnancy). Seven patients (3 F, 4 M, mean age: 34 ± 17 years) were selected: 4 patients after TBI (1 F, 3 M), 2 patients after stroke (1 F, 1 M) and 1 meningoencephalitis (F). Two of them (P5 and P7) never played computer games.

3.2 Procedure

We carried out the experiments according to the following procedures:

Experiment1:

- Familiarization session: each participant experiments 7 primary tasks (4 tasks : take an item and put it on somewhere; 3 tasks : take a container and fill it up with water);
- Assessment session: each participant experiments 1 among 8 configurations of the complex task;
- Questionnaire on material use and task understanding;
- Moreover, 3 participants on 13 tested the configuration interface in order to create various configurations of the complex task and filled out a questionnaire about the use of the configuration interface for therapist.

Experiment2:

- Familiarization session: each participant experiments 9 primary tasks (3 tasks : take an item ; 3 tasks : take an item and put it on somewhere; 3 tasks : take a container and fill it up with water);
- Assessment session:
    - Familiarization recall : each participant recalled 3 primary tasks (take a cup; take the bottle of milk and put it on the table; take the carafe and fill it up with water);
    - Assessment: each participant experiments 1 configuration of the complex task (Preparation of a black cafe during 20 minutes);
- Questionnaire on material use and task understanding;
- The virtual assessment grid was automatically filled out by the TVK software;
- The real assessment grid was filled out by therapist.

3.3 Data analysis

For both experiments, a descriptive analysis of the data was performed. In Experiment2, we did two comparisons: one comparison was about results of 3 PTs to find out patient's performance after one repeat on

©2010 ICDVRAT; ISBN 978 07049 15022

two sessions, the other comparison was about two assessment grids (real vs. virtual) to find out the difference and then to valid the virtual one. An analysis of questionnaire for each group (control group and patient group) was done to test the feasibility of the tasks and the software TVK.

4. RESULTS

4.1 Experiment1

All the 13 participants of the control group succeeded in completing the primary and the complex tasks. Particularly, we took into account the time needed to achieve the various tasks. Range of values are: 1) [31sec, 2 min 47 sec] for the primary task "take an item and put in on somewhere" during the familiarization session; 2) [40 sec, 3 min 40 sec] for the primary task "take a container and fill it up with water" during the familiarization session; and 3) [5 min 30 sec; 17 min 36 sec] for the various configurations of the complex task during the assessment session.

4.2 Experiment2

All the 7 patients succeeded in completing the primary tasks when they were asked to do them, except Patient 7 who failed on 3 primary tasks of the familiarization session. Particularly, we took into account the time needed to achieve the various tasks and the number of errors made by patients. A comparison on 3 primary tasks during familiarization session and familiarization recall in assessment session is showed on Figure 3 and Figure 4. In these two graphics, we found out their progresses according to mean time and number of errors on both sessions. That's mean that their capacities to perform the primitive tasks were maintained, see the improvement from the familiarization session to the assessment session.

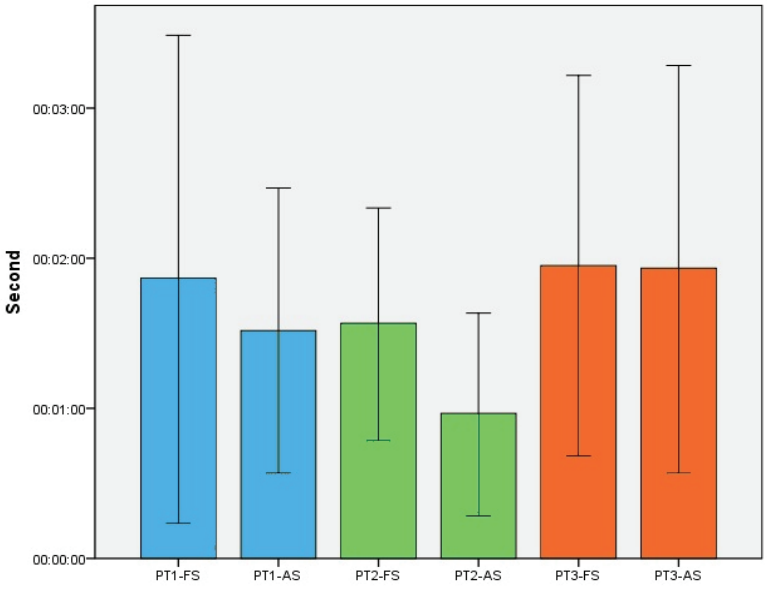


Figure 3. *Mean time of each primary task for 7 patients on both sessions (FS and AS)*

*FS: Familiarization session AS: Assessment session

*PT1: take a cup PT2: take the bottle of milk and put it on the table PT3: take the carafe and fill it up with water

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

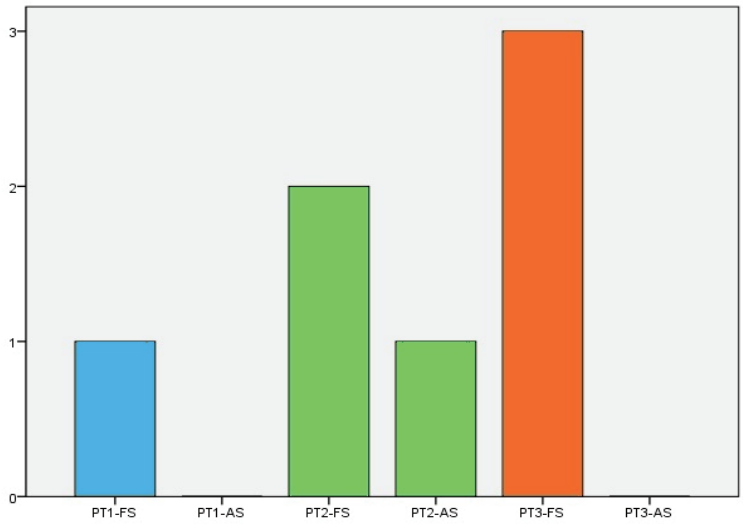


Figure 4. *Number of errors of 3 primary tasks for 7 patients on both sessions (FS and AS)*

In the assessment session, 5 patients on 7 succeeded in the completion of the CT (See details data in Table 1). The mean time of completion is 11 min 43 sec (± 7'37″). The patient6 did not repeat PTs before complete the CT. Finally, he had a problem to finish the task. The patient7 wasn't able to finish the CT at the end of 20 min. All of patients didn't disconnect coffee machine (Step 15).

Table 1. *Patients' data recorded of the task "coffee preparation" in the TVK*

N°	Age	Sex	Know PC games	Time (minute)	Number of errors	Number of executed steps		Omission
						Without errors	With errors	
1	20	F	well	4'33"	2	11	1	Step 15
2	19	M	well	2'45"	2	11	1	Step 15
3	48	F	medium	15'01"	9	9	3	Step 15
4	23	F	well	20"	21	8	4	Step 15
5	55	M	never	16'15"	6	8	4	Step 15
Mean				11'43"±7'37"	8±8	9±2	3±2	

* Number of executed steps (without and with errors) + omission = 13 (13 necessary steps to preparing a black coffee)

In the same virtual assessment for 7 patients, 40 errors were reported by the therapists in the real assessment grid (RG) and 61 errors were recorded by the TVK in the virtual assessment grid (VG) (Table 2). Comparison of these two grids is so complicated. But we tried to find out the difference between two grids. Our purpose is to unite therapists' interpretation in the TVK. There are two possibilities in the difference: missing of patient's errors and different interpretation between therapists. Research on missing of patient's errors isn't included in our study. For example, the patient4 realized 3 "Control errors": measured water for 8 people instead of 3; put 6 spoons of coffee in the coffee machine; poured 2 cups of coffee. But her therapist didn't note anything in the RG. Different interpretation between some therapists and the TVK is our research pivot. We list some differences below:

- After patient's correction, some therapists interpret still errors. The TVK don't record "actions omissions" after correction (e.g., the patient3 tried to turn on the coffee machine before fill up with water. Finally, she corrected).
- When one person didn't finish the task, some therapists stop interpreting immediately. But the TVK put an "omission" for all rest steps. For example, the patient7 wasn't able to finish the task at the end of 20 min.
- In order to interpreter the error "Action not completed", it must to definite an initial action and a terminal action for each step. So there are some different definitions of initial actions or terminal actions between therapists. For example, the TVK recorded an "Action not completed" for the patient7 on the step1 (take water) because he didn't close the coffee carafe before put it on the coffee machine. But his therapist didn't interpret as an error.

©2010 ICDVRAT; ISBN 978 07049 15022

- There is a different definition about the error "Actions additions" between the TVK and some therapists. In general, it should not touch all objects except for the coffee task. If you touch a useless object, that must be noted as an "Action addition". For the TVK, useless objects don't include wall, table, cupboard, etc.
- About the type of errors "Perseveration", if a patient tries to turn on the coffee machine *several* times before connect it (the button doesn't change the color to red), the TVK interpret 1 "perseveration". But most of therapists don't think so. The patient4 and the patient5 currently are the case.

We have to explain why the number of errors in two grids was the same for the patient1: because her therapist (one of authors) participated in the design of the TVK. For the patient6, there is zero error in the RG and 6 errors in the VG. We can't simply say that these 6 errors are 'true' errors or 'false' errors. It just depends on therapist. This difference between the real and the virtual assessment will help the Kerpape therapists to unite their interpretation of errors.

Table 2. *Number of errors in two assessment grids (real grid and virtual grid)*

N° P	Actions omissions		Actions not completed		perseveration		Sequence errors		Actions additions		Error recognition		Control errors		Difficulty in decision making		Dependence		No use of therapist"s help		Total	
	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG	RG	VG
1	*1*	*1*															*1*	*1*			*2*	*2*
2		1						1													0	2
3	7	1						5				1	1	2							8	9
4	2	1				1	3	3	3	1	3	3		3			9	9			20	21
5	2	1				1		3			1	1									3	6
6		2		1										2				1			0	6
7	2	6		1				4	1								4	4			7	15

* When RG=VG, the number of errors is in red and Italic

After an analysis of two questionnaires filled by health subjects and patients with brain injury, we found out that:

- The parameter setting of the configuration (time constraint, number of cups of coffee to prepare, positions of objects) is very useful for therapist.
- The PTs and the CT are understandable and interesting for two groups.
- The use of materials and interaction are very simple for the people who had computer games experience. It's moderately difficult for the others.
- Different helps (mouse visual cues, display instruction on screen) are understandable even for patients without experience.
- The task "coffee preparation" is not useful for everybody because 2 patients on 7 don't usually drink coffee.

4. DISCUSSION AND CONCLUSIONS

We reported a preliminary study that validates the feasibility of the TVK with healthy subjects and patients after stroke or TBI as well as the delivery of a final virtual scale of evaluation based on the traditional scale used in the Kerpape Rehabilitation Center. The experimental results obtained support our hypothesis. 1) It's possible to computerize a daily life task (coffee preparation). It really worked in the TVK. 2) Patients with brain injury or health subjects are able to complete the virtual CT. Interestingly, the use of materials and virtual interaction are not very difficult for some patients. It's not like we suppose before. It's depends on the participant (health subject and patient) who has or hasn't computer games experience. In this study, we had two difficulties on real and virtual assessment. Actually on real assessment, it's difficult to unite define and accurate measure errors for therapist. The variability of interpretation of errors by the therapists was protruded. On virtual assessment, it's difficult to observe behavioral errors (e.g., not appropriate behavior) for a simple computer system because their interpretation is still too subjective. This research has

©2010 ICDVRAT; ISBN 978 07049 15022

investigated again the potential of using VR in therapeutic area: identification and characterization of deficits; subjective measure; performance review and unite interpretation of errors for all therapists.

The Kerpape therapists are providing their assessment grid and uniting interpretation of errors. The achievement of these developments will provide novel therapeutic practices to our clinical partners. Two future goals are to provide software compatibility with instruments that allow collection and analysis of behavioral data, such as eye-tracking devices and sensors for psycho-physiological monitoring and to investigate how capacities learned in a virtual task can be generalized to the same task in the real world.

Acknowledgements: We thank Laval authorities (Laval Agglomération and Conseil Général de la Mayenne) for their support and Emissive company for the 3D modeling of the TVK.

5. REFERENCES

B M Brooks, F D Rose, J Potter, S Jayawardena and A Morling (2004), Assessing stroke patients' prospective memory using virtual reality, *Brain Inj*, **18**, 4, pp.391-401.

R C Davies, E Löfgren, M Wallergard, A Linden, K Boschian, U Minör, B Sonesson and G Johansson (2002), Three Applications of Virtual Reality for Brain Injury Rehabilitation of Daily Tasks, In *International Conference on Disabilities, Virtual Reality and Associated Technology*, Hungary.

C M Fidopiastis, C B Stapleton, J D Whiteside, C E Hughes, S M Fiore, G A Martin, J P Rolland and E M Smith (2006), Human Experience Modeler: context-driven cognitive retraining to facilitate transfer of learning, *Cyberpsychol Behav*, **9**, 2, pp.183-7.

S Fortin, L Godbout and C M Braun (2003), Cognitive structure of executive deficits in frontally lesioned head trauma patients performing activities of daily living, *Cortex*, **39**, 2, pp.273-91.

O Godefroy (2003), Frontal syndrome and disorders of executive functions, *J Neurol*, **250**, 1, pp.1-6.

A S Jouadé (2003), Evaluation écologique de l'exécution de routine d'actions chez des patients dysexécutifs., In, Edition30. Mémoire de Diplôme d'Etudes Appliquées à l'Université d'Angers.

N Katz and A Hartman-Maeir (2005), Higher-level cognitive functions, In *Cognition and occupation across the life span* (N Katz), AOTA Press, Bethesda, MD, pp.3-26.

E Klinger, I Chemin, S Lebreton and R M Marié (2006), Virtual Action Planning in Parkinson's Disease: a control study, *Cyberpsychol Behav*, **9**, 3, pp.342-347.

E Klinger, X Cao, A S Douguet and P Fuchs (2009), Designing an ecological and adaptable virtual task in the context of executive functions, In *Studies in Health Technology and Informatics (SHTI) series* (B Wiederhold and G Riva), pp.248-252.

P Pradat-Diehl, A Peskine, M Chevignard, C Taillefer, C Picq, F Poncet and P Pradat-Diehl (2006), *Évaluation des troubles neuropsychologiques en vie quotidienne*, Springer Paris, Paris.

A A Rizzo, M T Schultheis, K A Kerns and C Mateer (2004), Analysis of assets for virtual reality applications in neuropsychology, *Neuropsychol Rehab*, **14**, pp.207-239.

A A Rizzo, T Bowerly, J G Buckwalter, D Klimchuk, R Mitura and T D Parsons (2006), A virtual reality scenario for all seasons: the virtual classroom, *CNS Spectr*, **11**, 1, pp.35-44.

F D Rose, B M Brooks and A A Rizzo (2005), Virtual reality in brain damage rehabilitation: review, *Cyberpsychol Behav*, **8**, 3, pp.241-62; discussion 263-71.

L Zhang, B C Abreu, G S Seale, B Masel, C H Christiansen and K J Ottenbacher (2003), A virtual reality environment for evaluation of a daily living skill in brain injury rehabilitation: reliability and validity, *Arch Phys Med Rehabil*, **84**, 8, pp.1118-24.

©2010 ICDVRAT; ISBN 978 07049 15022

Traumatic brain injury memory training: a virtual reality online solution

P Gamito[1,3], J Oliveira[1], J Pacheco[2], D Morais[1], T Saraiva[1], R Lacerda[2], A Baptista[1], N Santos[1], F Soares[1], L Gamito[1,3], P Rosa[1,4]

[1]Faculty of Psychology, University Lusófona of Humanities and Technologies, Campo Grande, 378, Lisbon, PORTUGAL

[2]Centre of Medical Rehabilitation of Alcoitão, Rua Conde Barão, Alcoitão, PORTUGAL

[3]Clinic of São João de Deus, Rua António Patrício, 29, Lisbon, PORTUGAL

[4]CIS, ISCTE/IUL, Avenida das Forças Armadas, Lisbon, PORTUGAL

pedro.gamito@gmail.com

[1]*www.ulusofona.pt,* [2]*www.scml.pt,* [3]*www.saojoaodedeus.pt,* [4]*iscte.pt*

ABSTRACT

This study aims at assessing an online portal where patients with traumatic brain injury (TBI) can carry on memory and attention exercises outside clinic premises. The training took place in a VR setup where one TBI patient had to complete a set of 10 online VR sessions. The neuropsychological evaluation was carried out with the PASAT (Paced Auditory Serial Addition Task) at pre, during and after treatment assessments. The results showed an increase in working memory and attention levels from the first to the final assessment, which can suggest that VR applications may promote the autonomy and increase in overall quality of life of these patients. The average time for task conclusion was of 5 minutes.

1. INTRODUCTION

Patients suffering from Traumatic Brian Injuries (TBI) need, in most cases, to relearn almost all daily life activities (Wang et al, 2004). The consequences of TBI can be very severe and range from motor disability to cognitive impairment or attention/concentration deficits (Bäumer et al, 2001). The cognitive impairment is defined by Cooper et al (2008) as a limitation in capacity for mental tasks and is often associated with deficit on executive functions. The cognitive recovery after TBI is slow and difficult and, in most cases, involves training daily life activities (Wang et al, 2004).

Concerning the application of the new technologies on rehabilitation, the most promising advance may reside on the use of virtual reality in combination with Internet wideband in order to provide and support rehabilitation training. The use of 3D (3 dimensions) virtual environments offers the possibility of real-time feedback of subject's position and progression (Sveistrup, 2004). Concerning rehabilitation, its three core pillars: repetition, feedback and motivation may gain from the use of virtual reality (VR) (Holden, 2003). In rehabilitation, one of the most common procedures is the repeated and systematic training of the impaired functions (Allred et al, 2005). In agreement to the review from Sveistrup (2004), VR can provide training environments where repetition, visual and auditory feedback can be systematically manipulated according to individual differences. For Levin et al (2005) the use of VR applications in rehabilitation can be effective because of the 3D spatial correspondence between movements in the real world and movements in the virtual worlds which, in turn, may facilitate real-time performance feedback. Other studies (Cirstea & Levin, 2007), referred that performance feedback can provide information regarding impaired motor movements and according to Sveistrup (2004), the improvement of functional capabilities is better achieved with verbal or physical guidance actions for the patients.

The repetitive practice is also an important aspect in motor and cognitive training as it improves performance in disabled patients (Chen et al, 2004). These authors used VR environments in children with cerebral palsy and observed that the repetitive practice of a particular motor aspect enables the coordination of a specific muscular system. While, repeating the exercises, patients' senses are provided with feedback about the accomplishments achieved. For example, Feintuch et al (2006) developed a haptic-tactile feedback

©2010 ICDVRAT; ISBN 978 07049 15022

system that, when integrated on video-capture-based VR environment, enables patients to feel a vibration on their fingers whenever they "touch" a ball on the VR world. Viau et al (2004) analyzed movements performed by participants with hemiparesis with virtual objects in VR and real objects in real environments. These authors found no differences between the movements performed in VR and real environments and suggested that this VR technique can be an effective training for rehabilitation.

And because VR is usually presented on a multimodal platform with several sorts of immersive cues, such as images and sounds, patients are more willing to engage and pursue with the exercise. Bryanton et al (2006) found that when compared to conventional exercise, children with cerebral palsy had more fun and tended to repeat more often at home ankle dorsiflexion chair and long-sitting VR exercises.

VR seems, during hospitalization, to promote a more intensive and program supportive approach to the execution of the exercise, providing appropriate feedback to the patient. Also, exercises may be displayed with an adapting degree of difficulty, making possible the use of non-invasive forms of physiological monitoring. VR, in addition, gives therapist the ability to individualize treatment needs, while providing the opportunity for repeated learning trials and offer the capacity to gradually increase the complexity tasks while decreasing therapist support and feedback (Weiss & Katz, 2004). VR is a promising response to shorter hospitalization and foster homecare (Giorgino et al, 2008).

Studies on VR rehabilitation are usually focused on motor rehabilitation following brain damage and on training people with intellectual disabilities (Attree et al, 2005). However, VR has been also applied to rehabilitate patients that had suffered traumatic brain injuries (TBI). Slobounov et al (2006) found VR to be useful as a tool to assess brain concussion. A VR system was developed to inspect the temporal restoration of the effect of visual field motion on TBI's subjects with short term and long term balance anomalies. The study of memory and attentional problems is important for many patients with a history of TBI, even when they are not a primary problem. Wilson et al (2006) stresses that the automaticity of basic movement skills are often learned in controlled environments. Once the patient is required to apply skills in real-world settings, demands on attention and on working memory often exceed their processing and response capabilities. Also, skills' compliance in the previous stages of rehabilitation is inhibited by disruptions to attention and working memory processes. Patients with acquired brain injuries may find it tricky to train both a primary task (e.g. walking) and a simultaneous secondary task (e.g. signal detection). During the skill learning phase, the function of attention and memory can be supported by visual and verbal cues that can signal attention to obstacles and forthcoming events. Nevertheless, the use of attention and memory training with therapeutic purposes using VR, with TBI patients, is not yet clear (Sveistrup, 2004).

The wideband technology provides mobile and remote application of the 3D virtual environments brought about a new area of application: telerehabilitation. Due to the disability characteristics or to the distance from the rehabilitation clinic, or both, an important part of the patients neglect training sessions (Sugarman et al, 2006). Telerehabilitation may take the exercises to the patients. Lewis et al (2006) developed a telerehabilitation application that enables therapist to communicate, control and monitoring patients' exercises remotely. This system comprises rehabilitation devices such as gloves and HMD on the patient's side and a web camera and headphones on the remote therapist side. However, it requires the effective participation of the therapist. This may be overcome by the replacement with an avatar. This synthetic person, armed with artificial intelligence, can coach the patient throughout the rehabilitation exercises dismissing therapist's involvement. Despite the increasing studies on this subject there are not many controlled studies that prove the efficiency of VR when it comes to rehabilitation (Holden, 2003). However, on all of them (Todorov et al; Rose et al; Brooks et al; Webster et al, cit in Holden, 2003), subjects performed better on VR set-ups than on real life exercises

Furthermore, there is lack of information regarding to the effectiveness of this approach on web based systems. Actually, there are several studies that are evaluating the effectiveness of offline virtual environments on rehabilitation training (Liebermann et al, 2006). However, and to our best knowledge, studies on the use of VR over an online platform for telerehabilitation and TBI purposes are still missing.

2. METHOD

2.1 Participant

One 20 years old male patient with memory and attention deficits resulting from TBI was recruited at the rehabilitation hospital Centro de Medicina da Reabilitação do Alcoitão. Neuropsychological screening was performed using the Wechsler Memory Scale-III (WMS). On the other hand, TBI severity was estimated with the Glasgow Coma Scale (GCS) that revealed a severe TBI level within 48 hours after injury.

©2010 ICDVRAT; ISBN 978 07049 15022

The inclusion criteria were as follows: a) diagnosed with TBI between three and twelve months after the injury; b) clinical deficit in memory and attention; c) from both genders between 18 and 60 years old. Exclusion criteria: patients with previous psychiatric disorders that may have an impact on memory and attention, such as drug addiction behaviors or severe depression, as well as neurological diseases, namely dementia in its possible various forms.

2.2 Measures

Neuropsychological deficits were diagnosed through the WMS-III (Wechsler, 1997) based on working memory subscale.

TBI severity was classified according to the GCS (Teasdale, Jennett, 1974). The GCS is the most widely used instrument for neurological assessment after TBI. This instrument is divided into three subtests, for eye opening response, verbal response and motor response. TBI severity is classified in a score that range from 3 to 15, where 3 corresponds to deep coma and 15 to fully awake and conscious subject.

The neuropsychological assessment for this experiment was divided in three phases: PTA – Pre-Treatment Assessment (session 1); ITA – Intermediate Treatment Assessment (session 5) and POSTA – Post-Treatment Assessment (session 9). The assessment was conducted by the Paced Auditory Serial Addition Task (PASAT) for neuropsychological evaluation of working memory and attention. The PASAT consists of two auditory lists of single numbers with a total of 60 numbers for each trial, presented in sequence with an inter-stimulus interval of 3 and 2 seconds, respectively. The patient has to listen to consecutive numbers and to verbally respond with the sum of each number. Because the PASAT requires the ability to retain information during extended periods of time, the test can be used to assess sustained attention and working memory processing.

In order to evaluate task performance, behavioral assessment was also performed. The completion time of each task was registered and used further as an indicator of task performance speed.

2.3 Procedures

This study took place in a room of the Psychology Department of the Centro de Medicina de Reabilitação de Alcoitão, Lisbon, Portugal. The patient was selected from the Rehabilitation Ward after acquiring memory and attention deficits from a motor vehicle accident.

The VR platform consisted on a small town populated with digital robots (bots). The town comprised several buildings arranged in eight squared blocks, along with a 2 room apartment and a mini-market in the surroundings, where the participant was able to move freely around and to grab objects, if wanted. The platform was developed using Unity 2.5.

The patient interacted with the VR worlds through an eMagin Z800 HMD (Head Mounted Display), moving around by pressing the left mouse button. For grabbing the 3D objects, the patient needed to press the f key on the laptop keyboard. Patient's avatar was spawned in the apartment's bedroom, from where he accomplished each session tasks by moving towards the final goal described further on. The HMD was hooked up to a 16'' ASUS M60 V with a 1GB ATI Radeon 4650 graphic board. The therapist role was to explain sessions' procedures and to assess the session outcome.j

The VR-based tasks consisted of 10 VR online sessions, such as follows:

Session 0: training interaction;

Session 1: daily life activities such as morning hygiene and breakfast, and working memory task such as finding the way to the minimarket and buying one item) (Figure 1);

Session 2: session 1 + working memory task: finding the way to the minimarket and buying several items (Figure 2);

Session 3: visuo-spatial orientation task I: finding the way from the minimarket back home (Figure 3);

Session 4: session 1 + visuo-spatial orientation task II: finding a different way to the minimarket (Figure 4);

Session 5: session 1 + a selective attention task I: finding a yellow dressed virtual character (Figure 5);

Session 6: session 1 + a selective attention task II: finding the door number 29 (Figure 6);

©2010 ICDVRAT; ISBN 978 07049 15022

Session 7: session 1 + a recognition memory task: retention of outdoor advertisements (Figure 7);

Session 8: session 1 + calculation and digit retention tasks: Mini-Mental State Examination (Folstein et al, 1975) and Short test of Mental Status (Kokmen et al, 1991) tasks along the way (Figure 8);

Session 9: visuo-spatial orientation task III: spawned on a different local of the VR world, the patient had to find his way back home with an item bought at the minimarket (Figure 9).

Figure 1. *Daily life activities.*

Figure 2. *Working memory task.*

Figure 3. *Visuo-spatial orientation task I.*

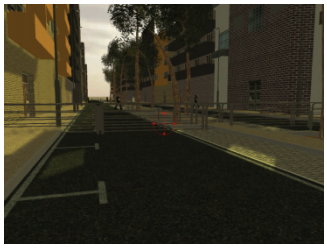


Figure 4. *Visuo-spatial orientation task II.*

Figure 5. *Selective attention task I.*

Figure 6. *Selective attention task II.*

Figure 7. *Recognition memory task.*

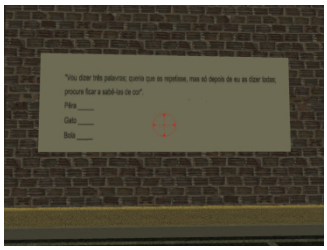


Figure 8. *Calculation and digit retention tasks.*

Figure 9. *Visuo-spatial orientation task III.*

3. RESULTS

PASAT data were analyzed for the corrected responses on each assessment (PTA, ITA, POSTA) for both trials – PASAT 3s and PASAT 2s. Values were considered significant for $p<0,05$.

Non-parametric pairwise comparisons were carried out by the χ^2 adjustment statistic to analyze the percentage of correct responses between assessments for both PASAT trials (3 and 2 seconds inter-stimulus intervals). For the first trial (Figure 10), data showed a significant increase in the percentage of correct responses between PTA and ITA ($\chi^2(1, 59) = 23,438$; $p < 0,001$), and between ITA and POSTA ($\chi^2(1, 59) = 41,667$; $p < 0,001$).

Regarding the second trial (Figure 11), data also revealed a significant increase in the percentage of correct responses between PTA and ITA ($\chi^2(1, 59) = 4,356$; $p < 0,05$), and between ITA and POSTA ($\chi^2(1, 59) = 5,689$; $p < 0,05$).

This means that the memory and attention exercises conducted on the VR world led to an improvement of the working memory and attention of this patient.

©2010 ICDVRAT; ISBN 978 07049 15022

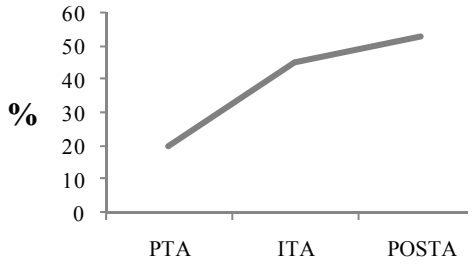


Figure 10. *Percentage of correct responses between assessments for the first PASAT trial (3s)*

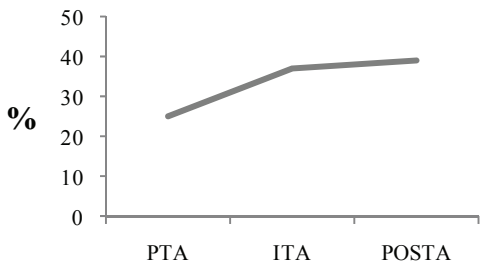


Figure 11. *Percentage of correct responses between assessments for the second PASAT trial (2s)*

Descriptive analyzes showed that the average completion time for each task was approximately of 5 minutes.

4. CONCLUSION

The main goal of this study was to assess an online VR platform for cognitive telerehabilitation of TBI patients. A preliminary VR session was conducted in order to evaluate possible navigation and interaction issues with the environment. The patient was able to achieve a satisfactory level of performance after some practice, with an average time for each task of 5 minutes. These data revealed a significant increase in working memory and attention levels, suggesting an improvement on patient cognitive function, which is in line with other studies that used VR platforms to increase memory and attention (Liebermann et al, 2006).

The importance of an online rehabilitation rests upon the ability to enable home training for patients that are far from the rehabilitation clinic or, for patients that still need to go to the clinic for training purposes. Other advantage resides on the ecologically validity of the training set. Being an immersive and interactive training, the fastidious repetition of traditional training is reduced. On a VR set, training is perceived more as a game and less than a task and can be considered as more engaging and more stimulating than the conventional methods (Stansfield, Dennis & Suma, 2005).

However, only with a larger sample it would be possible to fully assess and understand the impact of training memory and attention on TBI patients over a VR online setting. Also, the dissemination of game platforms such as Wii®, Xbox®, Playstation 3®, may contribute to a enhanced and more user-friendly training environments. And one should not forget that for future generations, the PC and its peripherals will be no longer a strange element. Most of the resistance of this type of intervention may result on the suspicion, of both patients and therapists, in using information technologies.

5. REFERENCES

Wang, P., Kreutzer, I.A., Bjärnemoa, R. & Davies, R.C (2004). A Web-based cost-effective training tool with possible application to brain injury rehabilitation. *Computer Methods and Programs in Biomedicine*, **74**, pp. 235—243.

Bäumer, M., Schneider, H., Frank, B. & Wallesch, C.W. (2001). Physician's estimates of rehabilitation requirements after stroke and traumatic brain injury. A: Questionnaire Survey in East Germany. *Disability Rehabilitation*, **23**, 7, pp. 306—312.

Cooper, R.A., Dicianno, B.E., Brewer, B., LoPresti, E., Ding, D., Simpson, R., Grindle, G. & Wang, H. (2008). A perspective on intelligent devices and environments in medical rehabilitation. *Medical Engineering & Physics*, **30**, pp. 1387–1398.

Sveistrup, H. (2004). Motor rehabilitation using virtual reality. *Journal of NeuroEngineering and Rehabilitation*, pp. 1-10.

Holden, M., (2005). Virtual Environments for Motor Rehabilitation: Review. *Cyberpsychology & Behaviour*, **8**, 3.

Allred, R.P., Maldonado, M.A., Hsu, J.E. & Jones, T.A. (2005). Training the "lessaffected" forelimb after unilateral cortical infarcts interferes with functional recovery of the impaired forelimb in rats. *Restor Neuroly Neuroscience*; **23**, pp. 297-302.

©2010 ICDVRAT; ISBN 978 07049 15022

Levin, M. F., Musampa, N. K., Henderson, A. K. & Knaut, L. A. (2005). New approaches to enhance motor function of the upper limb in patients with hemiparesis. *Hong Kong Physiotherapy Journal*, **23**, pp. 2-5.

Cirstea, M.C. & Levin, M.F. (2007). Improvement in arm movement patterns and endpoint control depends on type of feedback during practice in stroke survivors. *Neurorehabilitation and Neural Repair*, **21**, pp 1-14

Chen, Y., Kang, L.J., Chuang, T.Y., Doong, J.L., Lee, S.J. Tsai, M.W. et al. (2004). Use of Virtual Reality to Improve Upper-Extremity Control in Children With Cerebral Palsy: A Single-Subject Design. *Physical Therapy*, **87**, 11 pp 1441-1457.

Feintuch, U., Raz, L., Hwang, J., Yongseok, J., Josman, N., Katz, N., Kizony, R., Rand , D., Rizzo, A.A., Shahar, M. & Weiss, P.L. (2006). Integrating haptic-tactle feedback into a video capture based VE for rehabilitation. *CyberPsychology & Behavior*, **9**,2, pp 129-135.

Viau, A., Levin, M.F., McFadyen, B.J., Feldman, A.G. (2004). Reaching in reality and in virtual reality: a comparison of movement kinematics. In *Proceedings of the 15th International Society of Electrophysiology and Kinesiology Congress*, **51**.

Bryanton, C., Bossé, J., Brien, M., Mclean, J., McCormick, A., Sveistrup, H. (2006). Feasibility, Motivation, and Selective Motor Control: Virtual Reality Compared to Conventional Home Exercise in Children with Cerebral Palsy. *CyberPsychology & Behavior*, **9**,2, pp. 123-128

Attree, E.A., Brooks, B.M., & Rose, F.D. (2005). Virtual environments in rehabilitation and training: international perspectives. *Cyberpsychology and Behavior*, **8**,3, pp. 187–188

Slobounov, S., Slobounov, E. & Newell, K. (2006). Application of Virtual Reality Graphics in Assessment of Concussion. *Cyberpsychology and Behavior*, **9**,2, pp. 188–191.

Wilson, PH, Thomas, P., Sum, D., Duckworth, J., Gugliemetti, M., Rudolph, H, Mumford, N. & Eldridge, R. (2006). A multilevel model for movement rehabilitation in Traumatic Brain Injury (TBI) using Virtual Environments. IEEE, *5th International Workshop of Virtual Rehabilitation* (IWVR 2006).

Sugarman, H., Dayan, E., Weisel-Eichler, A., Tiran, J. (2006). The Jerusalem TeleRehabilitation System, a new Low-Cost, Haptic Rehabilitation Approach. *Cyberpsychology and Behavior*, **9**,2, pp. 178–182.

Lewis, J., Deutsch, J., Burdea, G (2006). Usability of the Remote Console for Virtual Reality TeleRehabilitation: Formative Evalation. *Cyberpsychology and Behavior*, **9**,2, pp. 142–147

Liebermann, D.G., Buchman, A.S. & Franks, I.M. (2006). Enhancement of motor rehabilitation through the use of information technologies. *Clinical Biomechanics*, **21**, pp. 8–20.

Weiss, P.L. & Katz, N. (2004). Guest Editorial: The Potential of Virtual Reality for Rehabilitation, *JRRD*, **41**, 5, pp. 7-10.

Giorgino, T., Tormene, P., Maggioni, G., Cattani, B., Pistarini, C. & Quaglini, S. (2008) – «My Hearth's Neurological Rehabilitation Concept' – Technologies for Post-Stroke Treatment». *Cybertherapy &* Rehabilitation, 1, pp. 17-19.

Wechsler, D. (1997). *Wechsler Memory Scale—Third edition manual*. San Antonio, TX: Psychological Corporation.

Teasdale G. & Jennett B. (1974). *Assessment of coma and impaired consciousness*. A practical scale. Lancet;2, 7872:81-4.

Folstein, M.F., Folstein, S.E. & McHugh, P.R. (1975). "Mini-mental state": a practical method for grading the cognitive state of patients for the clinician. *Journal of Psychiatric Research*, **12**, pp. 189-198.

Kokmen E., Smith G.E., Petersen R.C., Tangalos E. & Ivnik R.C. (1991). The short test of mental status. Correlations with standardized psychometric testing. *Archives of Neurology*, **48**, 7, pp. 725–728.

Stansfield, S., Dennis, C. & Suma, E. (2005). Emotional and Performance Attributes of a VR Game: A Study of Children. *Studies in Health Technology and Informatics*, 111, pp. 515-518.

©2010 ICDVRAT; ISBN 978 07049 15022

Impact of the physical field of view on the performance in a purchasing task in the VAP-S for patients with brain injury

H Cherni[1], A Kadri[2], A Tarruella[3], C Le Roy[4], P A Joseph[5], E Klinger[6]

[1,2,6]Arts Métiers Paristech – LAMPA – EA 1427, Angers-Laval, FRANCE

[3,5]EA 4136, University of Bordeaux, FRANCE

[4]Kerpape Rehabilitation Center, FRANCE

[1]*Heni.CHERNI-0@etudiants.ensam.eu*, [2]*abdelmajid.kadri@angers.ensam.fr*,
[3]*annabelle.tarruella@chu-bordeaux.fr*, [4]*cleroy@kerpape.mutualite56.fr*,
[5]*pierre-alain.joseph@chu-bordeaux.fr*, [6]*evelyne.klinger@ensam.eu*

ABSTRACT

In VR-based cognitive rehabilitation, there is a particular interest in subject's performance in the virtual tasks in which the patients are engaged. This performance is function of many factors among which the characteristics of visual information delivered by the virtual system. This study was designed to examine the impact of the physical field of view (PFOV) on the performance in a virtual task in the Virtual Action Planning Supermarket (VAP-S) among patients with brain injury and control subjects. Results show that, for all the participants, there is no significant difference between the main VAP-S variables in two experimental configurations (large FOV and small FOV), except for the number of incorrect actions that increases in the small FOV situation. We conclude in suggesting some explanations about the impact of the PFOV on patient use of the visual VAP-S information.

1. INTRODUCTION

After stroke or traumatic brain injury, cognitive rehabilitation aims the recovery of autonomy thanks to training in Activities of Daily Living (ADL). Due to the frequent lack of efficient resources to deliver the necessary interventions for patients rehabilitation, therapists are interested in functional virtual environments (VE) (Rizzo et al, 2004) that afford the simulation of instrumental ADL, e.g. doing shopping in a virtual supermarket (Klinger et al, 2004). The information related to the task has to be delivered in an appropriate way by the virtual system in order to allow the patient to perceive it, to extract the best conclusions and thus to generate successful reactions. Given the necessary choice of an adequate device to display visual information, we are interested in the impact of the physical field of view (PFOV) on information perception and on the performance in the virtual task. PFOV refers to the observable space that is seen at any given moment by both eyes fixing right forward. Its range is about 120 degrees, surrounded on both sides by a 30 degrees crescent of monocular vision (Zanglonghi et al, 2000). It can be modified by varying the screen size. The use of the large screen is often accompanied with the intuition that such display affords a better presentation of the information and a stronger feeling of immersion. However there is a lack of research that demonstrates empirically how users benefit from the increased size of the screen (Ni et al, 2006a).

Miscellaneous works studied this question with healthy people, mainly in spatial memory tasks, adopting two approaches in the choice of the PFOV: the first one keeping a constant PFOV and the second one making vary the PFOV.

The first approach consists in maintaining a constant PFOV by adjusting the viewing distance to screens with different sizes (Figure 1). This configuration inducing the same FOV whatever is the size of the screens, the result is that objects seen under the same visual angle have exactly the same size on the retina whatever is their real size on the screen (Rodieck, 2003). So in this approach, the size of the information that the user perceives is the same in the various types of display.

©2010 ICDVRAT; ISBN 978 07049 15022

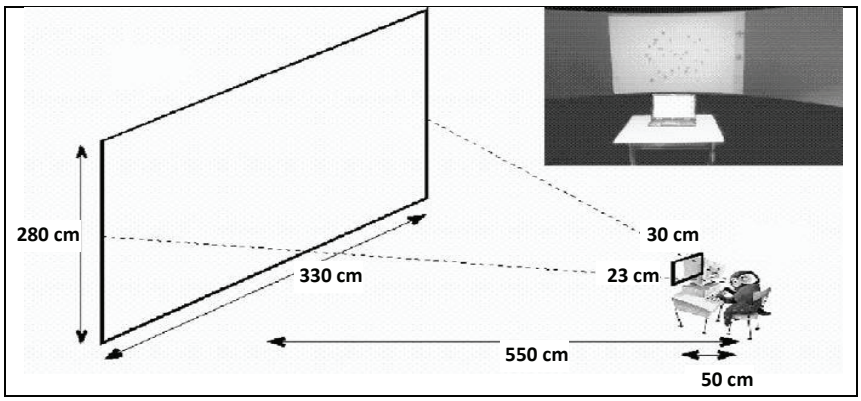


Figure 1. *Two screen sizes for a constant PFOV (variable distance).*

In their study, Patrick et al. involved 48 participants in a spatial recognition task in a VE for which they had to reproduce the cognitive card (Patrick et al, 2000). In this work, two configurations were implemented, leading to a PFOV of 42°. In the first one, users were placed at a distance of 0.69 m from a screen of 0.53 m width. In the second configuration, users were placed at a distance of 2.66 m from a projection screen of 3.35 m width. Their results showed that participants have a bad appreciation of distances in the small screen situation which may be due to the big variation of the PFOV because of user's head movements during the experimentation. In their works, Tan et al. designed two experimental conditions in which users were placed in front of screens of 0.36 and 1.93 widths at a distance of 0.64 m from the small screen and 3.45 m from the large screen, leading to a FOV of 52° (Tan et al, 2006). Participants were involved in two different tasks: a spatial orientation task in a 3D complex VE and a reading comprehension task. Results showed that in case of egocentric strategies (i.e. the user considers his point of view as if he is in the environment), the big screen allows the amelioration of user's performance in spatial orientation tasks. But no difference was found between the two configurations in the reading comprehension task.

The second approach consists in keeping the same viewing distance to two screens with different sizes in order to increase the PFOV and so the size of the objects on the retina (Figure 2). In their study, Ni et al. placed the user at about 0.61 m from two screens of 0.50 m and 1.20 m widths, inducing a FOV of 48° with the small screen and 90° with the large screen. Results showed that increasing the screen size, and thus the PFOV, improves the efficiency in spatial navigation tasks (Ni et al, 2006a).

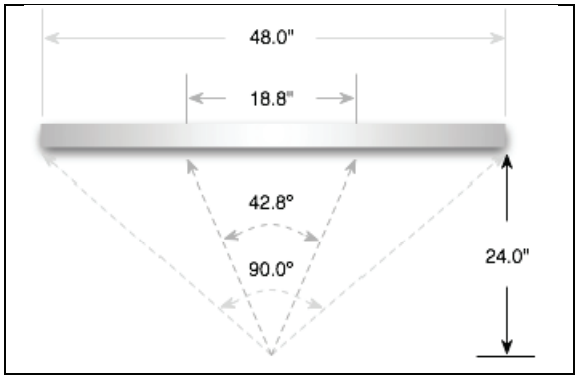


Figure 2. *Two sizes of screens for two PFOVs (constant distance).*

Through related works, we observed the important role attributed to the PFOV on tasks performance in VE. In order to design adapted VR-based training conditions for cognitive rehabilitation, we wish to study this question in the context of patients with brain injury. The main objective of this work is to study the impact of the PFOV on the performance in a shopping task in the VAP-S (Virtual Action Planning Supermarket) among control subjects and patients with brain injury.

©2010 ICDVRAT; ISBN 978 07049 15022

2. METHOD

2.1 Participants

Nine patients after stroke, hemiplegics at chronic phase, (1 M and 8 F, mean age= 54.3 ± 13.9) and twenty-two control subjects (12 M and 10 F, mean age= 29 ± 10.2) were included in our study.

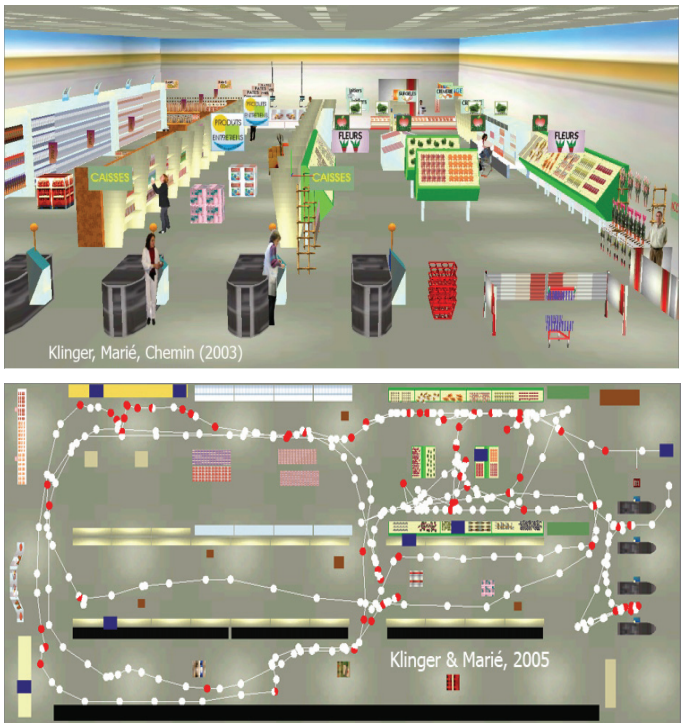


Figure 3. *The Virtual Action Planning Supermarket.*

2.2 Instrumentation

The VAP-S (Klinger et al, 2004; Klinger, 2006) was designed to assess and train the ability to plan and execute the task of purchasing items on a shopping list. Operating the VAP-S includes a series of actions, described as a task, and allows an analysis of the strategic choices made by clients and thus their capacity to plan, such as the "test of shopping list" (Martin, 1972). The VAP-S simulates a fully textured medium size supermarket with multiple aisles displaying most of the items that can be found in a real supermarket. There are also four cashier check-out counters; a reception point and a shopping cart. Some obstacles, like packs of bottles or cartons may hinder the advance of the shopper along the aisles. In addition, virtual humans are included in the supermarket such as a fishmonger, a butcher, check-out cashier and some costumers. While sitting in front of PC screen monitor, the participant enters the supermarket behind the cart as if he is pushing it, and moves around freely pressing the keyboard arrows. He is able to select items by pressing left mouse button. The test task is to purchase seven items from a clearly defined list of products, to then process to the casher's desk and to pay for them. Twelve correct actions (e.g, selecting the correct product) are required to completely succeed the task. Many variables can be calculated from the recorded data such as the total distance traversed by the patient, the total task time, the number of correct actions and the number of incorrect actions.

Many studies showed the efficiency of the VAP-S as a tool for cognitive assessment among various populations such as Parkinson disease (Klinger et al, 2006), Mild Cognitive Impairment (Werner et al, 2009), and Schizophrenia (Josman et al, 2009).

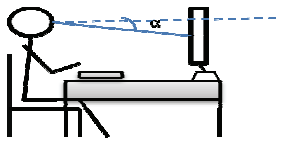
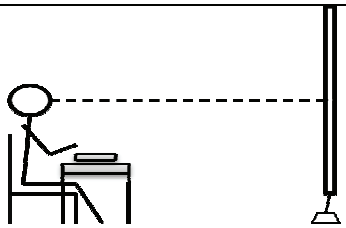
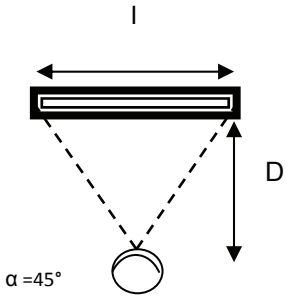
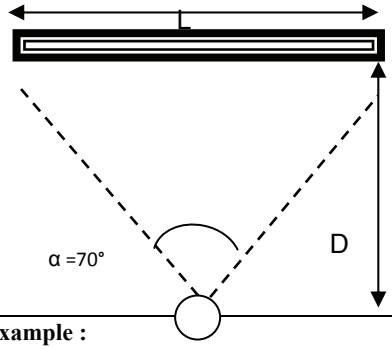
2.3 Experimental conditions

Our objective was to design two experimental conditions, one with a large screen (Config L) and the other with a small screen (Config S). In order to define the two configurations, we referred to the knowledge on human FOV (Zanglonghi et al, 2000) as well as on the VR-based studies that explored the relation between size of screen and the performance in VEs (Patrick et al, 2000; Tyndiuk et al, 2005; Ni et al, 2006a; Ni et al,

©2010 ICDVRAT; ISBN 978 07049 15022

2006b; Tan et al, 2006). We chose a pragmatic approach considering the means used in the university hospital of Bordeaux, so we used a video-projection on a classic wall screen. The PFOV was modified by adjusting two parameters: the size of the screen and the distance between the users and the screen. We found a limitation in increasing the PFOV: the distance between the patient and the screen had to stay long enough to not induce troubles with space exploration and head movements. For patients comfort we chose a PFOV of 70° for the large screen and 45° for the small screen (Table 1).

Table 1. *Experimental conditions: Config S (small screen, PFOV= 45°) and Config L (large screen, PFOV= 70°).*

	Config S	Config L
Position of the user in front of the screen	 The center of the screen is under the horizontal line containing the user eyes.	 The center of the screen belongs to the horizontal line containing the user eyes.
PFOV		
Distance from the screen **D = (L/2)/tg (α/2)**	**Example :** **If** L = 0.4m **then** : D= 0.48 m *(tg(22.5) = 0.414)*	**Example :** **If** L= 2 m **then** : D=1.43 m (tg(35)=0,7)

2.4 Procedure

All subjects carried out a familiarization session in which they had to buy 3 items geographically well distributed in the VAP-S. Then they were engaged in an assessment session: they had to purchase seven items from a clearly defined list of products without any time constraint. Each subject carried out twice the assessment session within a one week period: once in "config S" and once in "config L" ("S then L" or "L then S"). The comparison variables are the total distance traversed by the patient (DP), the total task time (T), the number of purchased items (NbA), the number of correct actions (BA), the number of incorrect actions (MA), the number of pauses (NbP), the duration of pauses (TP) and the time to pay (Tp).

2.5 Statistics

Descriptive data analysis (means, standard deviations, ranges) were used to describe the population and the main variables. Each subject being tested in two configurations, it is then an intra-subjects experiment (Kinnear and Gray, 2005). According to the type of the sample, we chose the t test to analyze the significance of the differences.

©2010 ICDVRAT; ISBN 978 07049 15022

3. RESULTS

Participants' data in their performance in the VAP-S are presented in Table 2 for the patients and in Table 3 for the control group. According to the results, it seems that the performance of the patients was better in Config L than in Config S. For example, the number of incorrect actions in Config S (33) is almost the double of the number of incorrect actions in Config S (18). The mean distance crossed in the task is also smaller in Config L (311 m) than in Config S (350 m). On the other hand, control group results were almost equivalent in both configurations except the number of incorrect actions which was significantly higher in Config S than in Config L.

Table 2. *Performance comparison between Config S and Config L in patients group*

Patients	Config S		Config L		P*
	Patients (1 M and 8 F)	Patients [range]	Patients (1 M and 8 F)	Patients [range]	
Age	54.3±13.9	[23 ; 67]	54.3±13.9	[23 ; 67]	-
NbA	7	[7 ; 7]	7	[7 ; 7]	-
BA	11±1.8	[7 ; 12]	11.5±1	[9 ; 12]	0.5
MA	33±30	[3 ; 111]	18±15	[3 ; 59]	0.1
Tp (sec)	4±2.9	[1.4 ; 11]	5.4±4.7	[1.6 ; 14.6]	0.3
DP (m)	350,5±137.1	[210 ; 578.4]	311,9±146.8	[147.5 ; 573.2]	0.4
T (min)	23.6±14	[7.5 ; 51.2]	22.8±14.5	[9 ; 55.9]	0.7
NbP	57±35	[17 ; 125]	50±30	[19 ; 114]	0.5
TP (min)	14.4±11.7	[3 ; 38.5]	14.3±13.1	[3.7 ; 45.3]	0.9

Bilateral signification : p<0.05 ➔ significant result

Table 3. *Performance comparison between Config S and Config L in control group*

Contrôles	Config S		Config L		P
	Controls N= 22 (10 F, 12 H)	Controls Extended value	Controls N= 22 (10 F, 12 H)	Controls Extended value	
Age	29±10.2	[22 ; 59]	29±10.2	[22 ; 59]	-
NbA	7	[7 ; 7]	7	[7 ; 7]	-
BA	12	[12 ; 12]	12	[12 ; 12]	-
MA	8±5.4	[3 ; 24]	3.65±3	[0 ; 17]	0.0
Tp (sec)	2.2±1.5	[0.3 ; 5.6]	2.1±1.4	[0.3 ; 5.6]	0.6
DP (m)	175,8±38.1	[135.2 ; 251]	171,7±29.3	[128 ; 261.7]	0.7
T (min)	5.7±1.5	[3.8 ; 10.3]	5.8±2.1	[4 ; 11.1]	0.1
NbP	13±5	[5 ; 22]	13±6	[4 ; 30]	0.3
TP (min)	2.09±2.73	[0.9 ; 3.56]	2.27±1.18	[0.75 ; 5.75]	0.3

Bilateral signification : p<0.05 ➔ significant result

©2010 ICDVRAT; ISBN 978 07049 15022

4. DISCUSSION

Results of our experiments show that, for all the participants, there is no significant difference between the main VAP-S variables in both configurations (Config S and Config L), except for the number of incorrect actions which doubles significantly from Config L to Config S. This increase can be explained by the fact that virtual objects are more visible when they are presented in the large screen in Config L. The participants use in a better way the visual VAP-S information displayed on a large screen. Besides, the stimuli which are source of information can also be source of confusion and slowing down if they are too numerous. Another explanation can be suggested: fewer errors occur in Config L because fewer stimuli are seen simultaneously. Moreover we may have expected that the number of stops (NbP) during the task will be higher in Config L, because subjects will stop more frequently in Config L to move their heads to explore the totality of the visual space in front of the large screen. Our results do not validate this expectation. We think that with a better perception of the information in Config L participants do not need to stop frequently to identify the virtual space and objects. We also compared our two groups of participants, and significant performance differences appear between the control group and the patient group. But these results are not evoked in this paper because the two groups are not matched in age.

5. CONCLUSION

This exploratory study is a first step of our research work that aims to identify the best visual interfaces for patients with brain injury. It allowed us to identify the impact of the PFOV on one of the principal variables in the VAP-S. Data collection is going on in order to increase the size of our samples and to get samples more homogeneous in age. Current and further results will be analyzed in order to list recommendations for the choice of display characteristics for experiments among patients with brain injury. This will allow us to find optimal presentations of virtual assessment tasks as well as rehabilitation tasks which avoid spending significant resources in non appropriated systems.

Acknowledgements: We thank Laval authorities (Laval Agglomération and Conseil Général de la Mayenne) for their financial support.

8. REFERENCES

N Josman, A E Schenirderman, E Klinger and E Shevil (2009), Using virtual reality to evaluate executive functioning among persons with schizophrenia: a validity study, *Schizophr Res*, **115**, 2-3, pp.270-7.

P Kinnear and C Gray (2005), *SPSS facile appliqué à la psychologie et aux sciences sociales*, Paris.

E Klinger, I Chemin, S Lebreton and R M Marié (2004), A Virtual Supermarket to Assess Cognitive Planning, *Cyberpsychol Behav*, **7**, 3, pp.292-293.

E Klinger (2006), Apports de la réalité virtuelle à la prise en charge des troubles cognitifs et comportementaux, In *Informatique*, Edition228. Paris: ENST.

E Klinger, I Chemin, S Lebreton and R M Marié (2006), Virtual Action Planning in Parkinson's Disease: a control study, *Cyberpsychol Behav*, **9**, 3, pp.342-347.

R Martin (1972), *Test des commissions (2nde édition)*, Editest, Bruxelles.

T Ni, D A Bowman and J Chen (2006a), Increased display size and resolution improve task performance in Information-Rich Virtual Environments, In *Proceedings of Graphics Interface 2006*, Quebec, Canada, pp.139-146.

T Ni, G S Schmidt, O G Staadt, M A Livingston, R Ball and R May (2006b), A Survey of Large High-Resolution Display Technologies, Techniques, and Applications, *Proceeding IEEE VR Conf*.

E Patrick, D Cosgrove, A Slavkovic, J Rode, T Verrati and G Chiselko (2000), Using a large projection screen as an alternative to head-mounted displays for virtual environments, In *CHI '00: Proceedings of the SIGCHI conference on Human factors in computing systems* ACM, New York, pp.478--485.

A A Rizzo, M T Schultheis, K A Kerns and C Mateer (2004), Analysis of assets for virtual reality applications in neuropsychology, *Neuropsychol Rehab*, **14**, pp.207-239.

R-W Rodieck (2003), *la vision*

©2010 ICDVRAT; ISBN 978 07049 15022

D Tan, D Gergle, P Scupelli and R Pausch (2006), Physically Large Displays Improve Performance on Spatial Tasks, *ACM Transactions on Computer-Human Interaction (ToCHI)*, **13**, 1, pp.71-99.

F Tyndiuk, G Thomas, V Lespinet-Najib and C Schlick (2005), Cognitive comparison of 3D interaction in front of large vs. small displays, In *Proceedings of the ACM symposium on Virtual reality software and technology*, Edition. Monterey, CA, USA: ACM.

P Werner, S Rabinowitz, E Klinger, A S Korczyn and N Josman (2009), The use of the virtual action planning supermarket for the diagnosis of mild cognitive impairment, *Dementia and Geriatric Cognitive Disorders*, **27**, pp.301-309.

X Zanglonghi, L Avital and N Prigent (2000), Champ visuel et expertise, champ visuel et aptitude à la conduite, *Réflexions phtalmologiques*, **5**, pp.32-36.

©2010 ICDVRAT; ISBN 978 07049 15022

Participatory design with children with autism

L Millen, S V G Cobb, H Patel

VIRART, Human Factors Research Group, University of Nottingham,
University Park, Nottingham, UK

{*emxlm; sue.cobb; harshada.patel*}*@nottingham.ac.uk*

www.virart.nottingham.ac.uk

ABSTRACT

The COSPATIAL (Communication and social participation: collaborative technologies for interaction and learning) project explores how we can develop effective and useful educational technologies in the form of shared active surfaces (SAS) and collaborative virtual environments (CVEs) to support the enhancement of social skills for children on the autism spectrum. The UK design team comprises technology developers, design engineers, educational psychologists as well as teachers from both mainstream and autism specialist schools. A user centred design approach is used to make decisions and review prototype development using CVE technology. The team is then involved in detailed specification of CVE scenarios and iterative review of prototypes. The involvement of teachers throughout the entire process is crucial, but in order to understand the primary user further and implement concepts optimally it is also desirable to involve the target end users directly in the design process. This paper describes the participatory design approach for elicitation of user requirements and CVE scenario design that is being used with typically developing children and how these methods have been adapted to facilitate involvement of children on the autism spectrum.

1. INTRODUCTION

Participatory design methods using a range of techniques have been successfully applied to workspace design and to the development of new technologies in industrial settings (Wilson et al., 2009). At the start of the participatory design process for new technologies in industrial settings, we have found it useful to generate participant enthusiasm and creativity through demonstrations of existing systems. This facilitates discussion, particularly amongst users who are unfamiliar with new technologies and their potential uses (Wilson et al., 2009). A variety of techniques are then used to provide information about user needs and requirements, and to generate and evaluate ideas for new technology design. Techniques used with adults in industrial settings include questionnaires, interviews, task analysis, observation, brainstorming, focus groups, storyboarding, technology demonstrations, exploratory user tests, and Wizard of Oz prototype review. In these contexts we have also found it useful to develop current practice scenarios and conceptual futuristic scenarios, use cases, and have produced detailed user requirements for prioritisation with the end users (Patel et al., 2006a; Patel et al., 2006b; Wilson et al., 2009). Our approach has always involved building close relations with the user partners, establishing who the stakeholders are and gaining an understanding of the contexts and skills to be investigated. The key has been to involve the users as much as is feasible, from concept design through to implementation of the technology.

In the context of education, there has been some discussion concerning the role that children are can take to inform design of instructional technology (Scaife and Rogers, 1999). Druin (2002) categorised the involvement of children in the design process of technology applications according to different roles, as: users, testers, informants or design partners and described how methods could be adapted to glean useful information from children of all ages to inform technology design (Druin et al, 1999). There are several examples of direct involvement of school children in the design process for development of new technologies (e.g. KIDSTORY: Druin et al., 2000) and these projects have made use of prototyping methods (such as building low tech mock-ups) to obtain children's design ideas and Wizard of Oz methods to facilitate review of potential design. Other researchers have moved from concentrating solely on children's involvement as design partners in the development of technology, to their role as 'experience design partners'. This considers the broader educational impact of the involvement of children in the design process. For example,

©2010 ICDVRAT; ISBN 978 07049 15022

the improvement in collaboration skills and goal orientated attitudes and critical thinking; and the transfer of skills and knowledge to new technological contexts (Garzotto, 2008).

The involvement of end-users directly in the design process can be useful to inform adequate design and it can be argued that it is more important for individuals with special needs to contribute to the product design process as advocates may not accurately represent their views (Fischer & Sullivan, 2002). However, this process can be difficult, particularly when the end-users have special needs that may affect their ability to communicate their views. The challenge of finding suitable methods for design input may be off-putting. Parsons and Mitchell (2002) note that individuals with autism are rarely involved in educational software development and this may be one reason why existing products are inadequate; '*User-centred design methodologies…address this concern somewhat because representative users are included in product design and development from the start*' (Parsons & Mitchell, 2002. P. 437).

Cobb et al (2002) describe the benefit of involving user representatives and professionals in the early conceptualisation stages of virtual environment development and recognised that different stakeholders inform different aspects of technology design; professionals (teachers) can help to define the purpose of the application and specification of learning objectives whereas end-user representatives provide an understanding of specific needs and requirements of the user group. Review of contribution to final prototype indicated that, although end users may be involved in idea-generation, they have less influence over final decisions for content of educational software (Neale, Cobb and Wilson, 2001). Users can, however, be directly involved in usability design decisions influencing interface design, content layout and interaction with a virtual environment learning scenario (Neale, Cobb and Wilson, 2002), Techniques for design input from different stakeholders are different at each stage of development and may need to be adapted to best elicit information from the end-user group. The 'inclusive design toolbox' for development of educational virtual environments describes different prototyping techniques and how these may be applied with different user groups to inform different aspects of software design (Neale, Cobb and Kerr, 2003).

Brown et al. (in press) involved stakeholders and user representatives during the analysis phase of their project which aimed to design location-based learning experiences for people with intellectual disabilities and additional sensory impairments. The design requirements derived from this early user participation were presented as conceptual storyboards displayed on an interactive whiteboard; groups of users provided feedback on these storyboards and initial prototypes were evaluated in facilitated user group sessions. At a later stage, a co-discovery method was employed with pairs of users to test the prototype system; this method collects information in real-time and may be suited to users with cognitive disabilities who may feel more comfortable working with a peer (Brown et al., in press).

Lalji and Good (2008) designed mobile phone interfaces for illiterate populations through a continuous partnership with the end user population, investigating their worlds, relationships and concerns and the context of the technology use. Non-typical users may have different interaction requirements and expectations of the technology, therefore it is important for their inclusion in the design process. User needs were elicited through the use of questionnaires, interviews, an exploration exercise (they were asked to make a dummy call using a landline), and participatory design sessions (participants were asked to draw menu icons). Lalji and Good adopted an iterative design and testing process by employing the use of questioning and probing, participatory design and testing of hardboard model prototypes which included the use of the 'think aloud' technique.

This paper presents the participatory design approach used for design and review of the COSPATIAL CVE scenarios. In particular, this paper focuses on methods used for participatory design with typically developing children and adaptations to these methods for children with autism spectrum conditions (ASC).

2. PARTICIPATORY DESIGN WITH CHILDREN

2.1 Introduction

As part of the COSPATIAL project we are developing a suite of programs using for collaborative interaction using CVE technology. The first in this series is a serious game called Block Party; a joint problem-solving, block building activity where each player has different but interdependent objectives to achieve. To complete the activity, children are paired with a peer and both access the same virtual environment from different laptops. The users are able to communicate with each other via their avatars. The Block Party task involves the children building a tower together out of blocks in the virtual environment. Each block is divided down the centre into two colours and child has a different target colour pattern that they have to achieve. In order to complete the task they therefore need to communicate with each other in order to jointly select a block with the colour combination that suits both of their needs.

©2010 ICDVRAT; ISBN 978 07049 15022

In order to evaluate both the learning potential and usability of the scenario a number of prototype review and scenario design sessions were arranged with typically developing children at a mainstream school. Six Primary School children (2 x 10 year olds, 4 x 11 year olds) took part in a 3-hour design workshop. This process would help us evaluate the usability of the prototype and enable us to trial and evaluate prototype review and scenario design methods try to understand implications for use with students with autism.

2.2 Critical review of prototype software

During these workshop sessions the students were encouraged to become critical testers and evaluators and they were briefed on the nature of design and prototyping. This discussion focused on the imperfections associated with prototypes and our requirement for, and the importance of, their critical feedback. In these situations, researchers and teachers must emphasise that children can be honest and should not tell us what they think we want to hear.

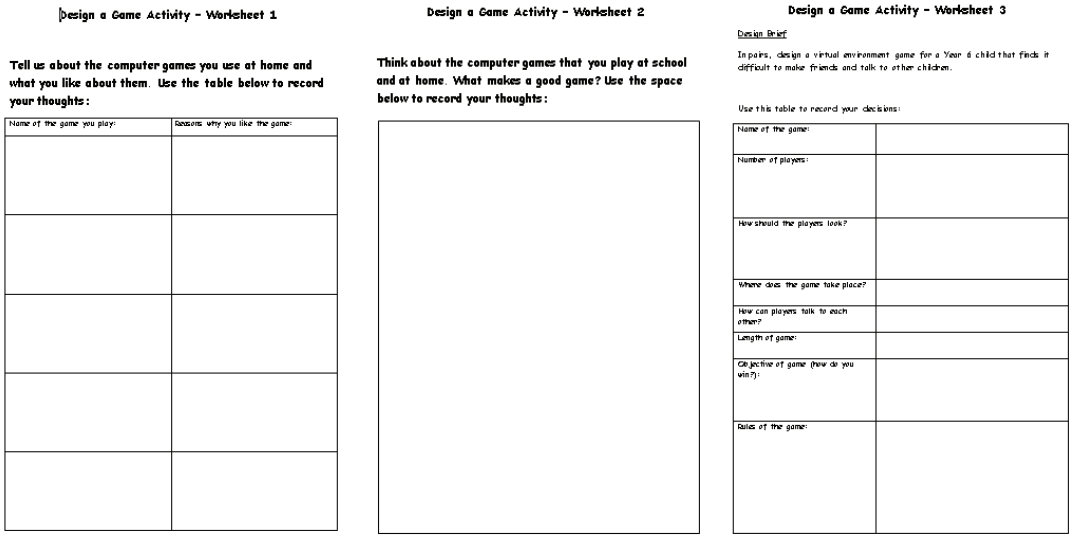


Figure 1. *Worksheets used in design workshop with typically developing children.*

The first task was to discuss in groups the computer games they use at home and what they like about them. The students were asked to record their responses on 'Worksheet 1' (Fig. 1). There were a variety of responses, e.g. "competing against friends", "never know what's going to happen next", "makes you think", "you get to design your own character". The discussion then moved on to 'Worksheet 2' (Fig. 1) and focused on what makes a good game Some responses to this included the use of colours, levels, rewards, tool bars, having a save button and many more ideas.

In order for the children to understand the type of technology the COSPATIAL project is using, a demonstration of the Block Party prototype was given. The children were encouraged to interact with the prototype and discuss positive and negative aspects of the game as they proceeded. The whole group then had a discussion to feedback their ideas and thoughts on the prototype. The teacher recorded their responses under the headings 'Like', 'Dislike' and 'Change'.

2.3 Scenario design

In the final stage of the session the students were set the task of developing their own ideas to design a computer game (Fig. 1 – worksheet 3). The students were provided with a design brief in which they were informed that they would be designing a game that would encourage a 12 year old child who finds it difficult to make friends to communicate with other children. To do this the students worked in small groups and completed a worksheet that detailed aspects of the game such as the aim, number of players and the rules. The students then went on to draw their game ideas on to large sheets of blank paper. The students were instructed to draw any part of their game ideas on the paper – this could be individual aspects such as how the avatars look or the whole game environment.

2.4 Observations and outcomes

The workshop activity session provided some fruitful discussion about what the students liked and disliked about various games. The children were actively engaged with each aspect of the afternoon and the ideas generated were many and varied. However, it became clear during the session that the scenario design task

©2010 ICDVRAT; ISBN 978 07049 15022

was fairly open-ended, the spectrum of ideas was vast. Students often had to be reminded of the overall aim of the computer game as their imaginations took them in many different directions. In some areas the activity was not constrained enough to gain information that could be directly fed back into concept elaboration.

3. ADAPTATION OF PARTICIPATORY DESIGN METHODS FOR CHILDREN WITH ASC

As one of the primary end users of the COSPATIAL technology, we want to also gain the input of students with autism spectrum conditions. The nature of autism presents particular difficulties with regard to idea generation and communication that could prohibit direct involvement of these children in the participatory design process. Taking into account specific characteristics of autism, and with advice from autism teachers, we adapted the participatory design workshop method described in the previous section to see if we could successfully involve children with autism in design and critical evaluation of the CVE scenarios.

3.1 Understanding user needs

Children with autism have a number of cognitive characteristics which may have implications when seeking to achieve user involvement with the design process (Hardy *et al*., 2002; Wing & Gould, 1979; Wing, 1996; Siegel, 2003; Baron-Cohen, 1996). These are summarised below (extracted from Millen et al, 2010. P. 153-154):-

- *limited language or communication skills* – this characteristic requires a considered approach when trying to involve the user in the process, particularly when attempting to generate and evaluate design ideas and eliciting user opinion;
- *poor imaginative skills* – this could cause potential difficulties, for example, when using low fidelity prototyping which requires the user to use their imagination skills to envisage the final product;
- *rigidity of thought processes* - People with autism find it difficult to be flexible in their thought processes and thus any changes to their environment or routine can prove difficult for them to understand or adapt to. This has implications for arranging sessions and disrupting routines;
- *"Theory of Mind" impairment*: the idea that people with autism often find it difficult or impossible to imagine another person's mental state and perspective – this poses the issue of whether a child with autism would be able to offer opinions based on their knowledge of their peers;
- *learning difficulties* – IQ or general level of ability or understanding may not be sufficient when dealing with the concepts required.

3.2 Adaptation of method

The freedom given to the typically developing students in the 'design a game' activity meant that they often forgot that the purpose of the game should be to encourage children to make friends. Observations of the mainstream school workshop, together with our prior knowledge about autism, led us to realise that this format would be far from ideal for students on the autism spectrum. The task should be more constrained and focused in order to encourage students with autism to participate, engage and benefit from the activity. Children with autism benefit from structured environments and activities. When presented with too many open-ended options the child may feel anxious or frustrated and becoming unwilling to participate in the activity. Clearly then, presenting a child with autism with a blank sheet of A2 paper and asking them to come up with computer game ideas is not an option.

In order to adapt the methodology to achieve this, the researcher met with an ICT specialist teacher with many years of experience of working with students with autism. This teacher also played an important role in developing a prototype feedback system to be used with students with autism. The format was later discussed further with a nurture teacher with numerous years of experience of working with children with communication difficulties and an autism specialist teacher from a mainstream school.

3.3 Prototype review with ASC

A Block Party review session was carried out with five students (16 and 17 years old) with autism spectrum conditions. This took place during the students' weekly ICT class and was facilitated by their ICT teacher. It was decided that the review of the prototype should be carried out as a group activity and would focus only on the initial training stage of the activity.

©2010 ICDVRAT; ISBN 978 07049 15022

The Block Party training scenario was projected via the interactive whiteboard in the classroom so that the whole group could see it. A keyboard and a mouse were connected to the laptop with an extension cable so that all students could have a turn to interact with the CVE from their seats. Each student was provided a feedback sheet that contained screenshots of various stages of the Block Party activity alongside columns that were headed 'Like', 'Dislike' and 'Not sure'. Feedback posters were placed on the wall next to the whiteboard – these were enlarged replicas of the individual feedback sheets (Fig. 3). These posters were used to collect the feedback from the whole group and were annotated by one student at a time with everyone's responses.

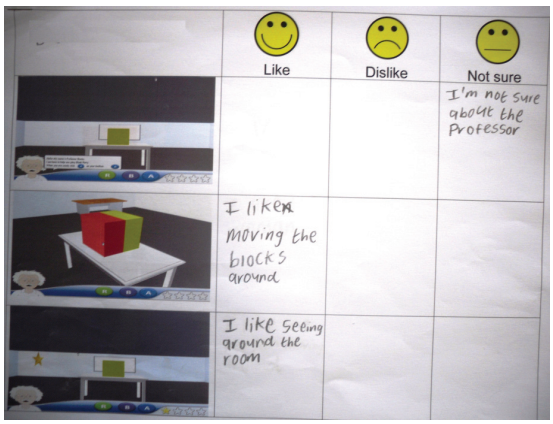


Figure 2. *Individual feedback worksheets used in prototype review with students with ASCs.*

The group played the training program by taking it in turns to take control or by suggesting to the teacher what action they should do next. At various stages the teacher paused the program and asked the group what they thought of the stage that they had just completed. These pauses corresponded to the screen shots on the feedback sheets. The students recorded their answers on their individual feedback sheets initially. The students were encouraged to provide both positive and negative comments down and were reassured that there was "no right answer". Some students may not have included comments but were not penalised for this as, for students with ASCs, a task requiring them to provide opinions and feedback is one that can be very difficult. Having said that, all of the students engaged very well with the activity and provided us with some interesting feedback. One student was then asked if they would record the group's comments on the posters.

3.4 Observations and outcomes

Overall the method used in this session was very successful. The session was sufficiently structured and supported by the teacher to meet the needs of students with ASCs. In fact, this method may be useful in gaining structured feedback from students in mainstream schools. The teacher stated that he thought the session documented here was successful due to the support provided in the previous introductory session. On the whole, the students navigated the virtual environment with ease and all of the students also said that they enjoyed the session and would like to play Block Party again.

One student struggled with a slight inconsistency between the screenshot on the worksheet and the actual view that the program had been paused at. In terms of method, it is important that worksheets and learning materials are consistent and accurate as students with autism are likely to pick up on the minor inconsistencies and struggle with them.

Although the session did highlight the fact that children with autism often pick up on very small inconsistencies that could cause problems, with the help and support of an experienced teacher these occurrences can be effectively managed and explained to the student. Time was spent in explaining to the students that the program was not finished and the person making the technology at the university wanted to know what they thought of it. Of course, ideally there would be no inconsistencies or problems within the program when demonstrating / using with students with ASCs. However, this session does suggest that holding these sessions with early, unfinished prototypes can be carefully and effectively managed.

3.5 Scenario design with ASC

The overall concept was the same as that used in the mainstream school 'design a game' activity. The activity was designed to be used by a researcher and a small number of students (two or three) with a teacher present. To aid understanding we hoped to support a progressive pattern of thinking that reflects the core components

©2010 ICDVRAT; ISBN 978 07049 15022

of the task. The activity was divided into six main sections (presented in Table 1). This structure encourages children to first think about the types of computer games that are available to them. They then proceed to consider what aspects of these games they like and dislike and subsequently they are asked to start generating computer game design ideas. The children and researcher talk together about what friends are and what makes a good friend, finishing the section by talking about why we might want to play computer games with our friends. The final two sections focus on designing a game. The children are asked to generate ideas for different aspects of game play and are then encouraged to draw some of these ideas.

The importance of flexibility is often highlighted when working with students with autism and is certainly a common theme in previous work that the authors have carried out on development of technology for children with autism. Consequently, although it is imperative that researchers approach these sessions organised and well prepared, there should always be an awareness that the method may need to change at short notice. For example, a session may need to be cut short due to the needs and attention span of the child or simply because the child may have experienced something upsetting that day and therefore unwilling to cooperate. Additionally, as the autism condition is a spectrum, the abilities of children with ASCs varies a vast amount and therefore the methods presented here may not be ability appropriate. The optimal way to respond to this is to always discuss and adapt plans with the school contact prior to the visit. The teacher should be able to indicate whether the activity is appropriate for the student and if it is not, how it can be made appropriate. Clearly, if a method is not working on the day the researcher must try to facilitate this process. This can be supported effectively if the student's teacher is present and active in the session.

3.6 Observations and outcomes

The scenario design method was trialled with three students with autism aged 13 and 14 years who are based at a mainstream secondary school. The activity was well received by the students who engaged in the session for approximately two hours. The session followed the pre-planned activity progression, however, the students had trialled our Block Party scenario during the previous day but did not have time to complete our student feedback form so this was completed at the start of the design a game session. It was originally anticipated that the activity would last only one hour but as the students were enjoying the activity the supervising teacher asked if we could continue on.

Although the teacher was close by and intermittently came to check on progress, the session was run by the researcher. The researcher had only met the students once the day before but this did not result in any problems and the students were happy to work and interact with the researcher. This is a huge advantage as in 'real world' research, and especially when working within the constraints of the school environment, there is often a shortage of time available for researcher acceptance and familiarity. Overall, the teacher was very impressed by the work carried out by the students. Initially, discussion was a little hard to generate but when presented with the drawing task the students became much more involved. One student in particular who is usually reluctant to engage in conversation was voicing extremely interesting ideas towards the end of the session.

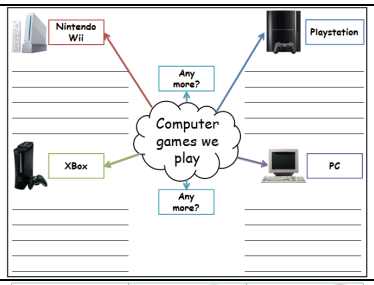
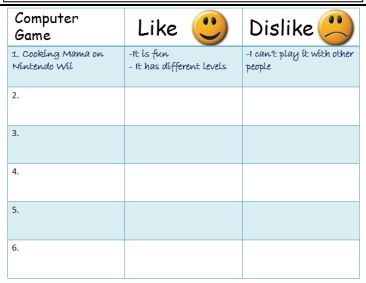
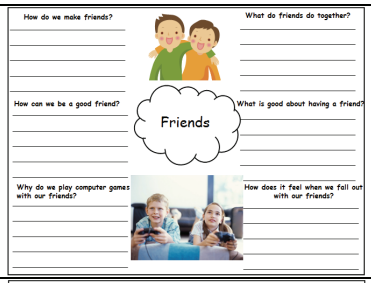
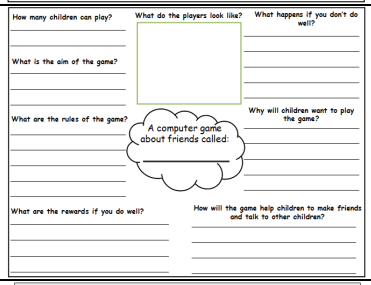
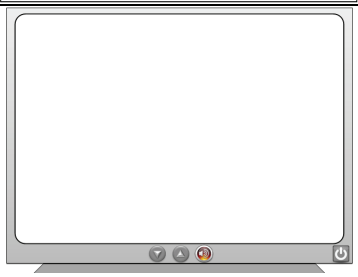
The use of personas had mixed results. Their presentation and content generated some discussion on who the characters were and the issues they struggled with and therefore proved beneficial in this sense. It is not clear whether the students held the personas in mind when engaging in the design task as the students did not refer to them. There was a little confusion regarding what the personas represented. When informed that the group would be designing the game for these fictional children, one student commented such 'But why? They're just on paper'. This is clearly an imagination related obstacle that needs more consideration. Another student commented 'Are they real people? Are we going to meet them?'. At this stage the teacher was present to help to clarify the concept and explained that these children were not real, but examples, however there are many children in the world who are like the examples that we are designing for. The use of this tool needs further consideration.

The researcher began this activity by asking the students to complete the 'Design a Game' mind map. Although this was a structured activity that focused on specific aspects of a game, the decision space for the students was still too vast and relied heavily on the use of imagination. With the students struggling to complete this work, the group took a break and returned to complete the final interface design drawing activity. Upon return, and as somewhat expected, the students were a little unsure about what they should draw on their blank paper. During the break the researcher sketched an example of a completed activity, a 'here's one I made earlier' prompt (as advocated for children with autism by Worth, 2005) in anticipation of this. This sketch was shown to the students along with an early prototype sketch of the Block Party game that they had played the previous day. The researcher explained the design process and that the group needed to draw their ideas so that the developer at the university could see them and use them for the new game (although, see section below on managing expectations). Although this seemed to clarify the task for the

©2010 ICDVRAT; ISBN 978 07049 15022

students there was still a reluctance to put pen to paper. For this reason the researcher offered to start the drawing off for them and was met with enthusiastic nods. The students requested that the game be set in a city and therefore the researcher sketched an outline of some tall buildings. This process engaged the students and they soon became happy to take over the drawing. Sometimes a student would complain that they could not draw something they way they wanted to and the researcher would step in. The students stayed on task for a full two hours and only needed gentle reminders of who the game was to be designed for a why. This is in contrast to the typically developing students at the mainstream school who needed many reminders of this.

Table 1. *Structure of workshop activities with ASC students.*

Activity	Worksheet	Description
1. Introduction to session	Visual timetable of activities	The researcher described the activities that would be conducted during the session. The timetable was displayed on the wall and activities were crossed off as each one was completed.
2. What computer games do we play?		A group discussion about the computer games that the children play at home and at school. Mind maps were used as part of this methodology as children with ASCs are often visual thinkers. A pre-prepared template was used to help the student understand what was expected of them – how much to write, where to write it and what to write about.
3. What do we like and dislike about the games we play?		The students were asked to choose five games from the previous activity and to think about their likes and dislikes for each game. To facilitate and prompt this, an example completed row has been provided. To end this activity, the researcher reviewed the answers with the students and prompted a discussion on what makes a good or bad game.
4. Friends		This activity focuses on friends and friendship as this is what we would like the students to base their ideas for a new game on. To facilitate this, a series of photographs were shown to the participants and they were asked to discuss whether the children in the photographs were friends or not, and why they thought this.
5. Design a game		The students were asked to design a computer game for other children to play. To do this they had to consider who the game was for, why someone would want to play it, what the game rules would be etc. To support this activity, simplified personas were used.
6. Interface design		In the final activity the students were asked to draw some of their game ideas from the previous stage. The students then drew their ideas directly on to the screen so that it represents how they would like the game to look. Students with ASCs may feel somewhat distressed by being presented with a completely blank sheet of paper (Worth, 2005) and therefore the outline of the computer screen is an attempt to place boundaries on the task.

©2010 ICDVRAT; ISBN 978 07049 15022

A number of interesting interface ideas were proposed by the group and after the drawing activity was complete the students were able to return to the previous, part-completed mind map and fill in the blanks. The researcher observed that, once started, the students were motivated by their own drawings and this created a domino-like effect of ideas. This meant that questions such as 'Why would children want to play the game?' and 'What happens if you do well?' were easy to answer subsequent to drawing activity. Perhaps this could be attributed to the tendency of children with ASCs to be much more visual learners and thinkers (Grandin, 2002).

In brief, this method is considered a success for a number of reasons including the depth of understanding of the task at hand, the quality of ideas generated by the students and the length of time spent on-task. However, issues such as the use of personas, the length of the activity and the large design-decision space presented need further consideration. These issues will be discussed further with the design team including teachers involved with the project. An alternative method could require students to design a specific and constrained aspect of the new CVE scenario e.g. what the avatars should look like, or how to present specific menus and toolbars. This will be investigated in upcoming sessions.

4. CONCLUSIONS

Involving users throughout the technology design process is important and useful. However few projects have involved children with ASCs. There are a number of established methods for involving adult users in the design process but there is little in the way of guidance for including users with such specific needs. The work reported here demonstrates that achieving the involvement of children with ASCs requires careful consideration and adaptation of techniques. Children with autism should not be excluded from the design process because of this and the early trials of our methods show positive results. The users are able to offer valuable insights into the design and evaluation of CVE technology. Not only is this process beneficial for us as a design team but it is also an important opportunity for the children where they are encouraged to voice their opinions, a skill that many children with autism struggle with. Many of the teachers who have been involved in COSPATIAL work have commented that the design sessions held have been hugely beneficial for the children.

Early work indicates that some of the methods used have potential when including children with ASCs in the design process. However, the methods are far from perfect and one of the biggest challenges for the involvement of users with autism in design their poor imagination skills. Future work will therefore aim to refine these methods. Other methods such as storyboarding and 3D low fidelity prototyping will also be investigated and evaluated for use with this user group.

Acknowledgements: COSPATIAL (2009-2012) is funded under the Seventh Framework Programme of the European Commission (http://cospatial.fbk.eu/). We thank our project partners at FBK in Italy, and the University of Haifa and Bar-Ilan University in Israel and our UK project partners at the University of Nottingham and the University of Birmingham. We also thank our collaborating schools in the UK; Rosehill, Sutherland House and Wadsworth Fields Primary School, Nottingham and King Charles I School, Kidderminster.

5. REFERENCES

Baron-Cohen, S. (1996) *Mindblindness: an Essay on Autism and the Theory of Mind*. Cambridge, Mass: The Massachusettes Institute of Technology Press.

Brown, D.J., McHugh, D., Standen, P., Evett, L., Shopland, N., and Battersby, S. (in press). Designing location-based learning experiences for people with intellectual disabilities and additional sensory impairments. *Computers & Education*, 1-10.

Bühler, C. (2001). Empowered participation of users with disabilities in R&D projects. *International Journal of Human-Computer Studies*, 55, 645-659.

Cobb, S.V.G., Neale, H.R, Crosier, J.K. and Wilson, J.R. (2002). Development and Evaluation of Virtual Environments for Education. In K. Stanney (Ed.), Virtual Environment Handbook, Chapter 47, Lawrence Erlbaum. 911-936.

Druin, A. (2002). The role of children in the design of new technology. *Behaviour and Information Technology*, 21(1), 1-25.

©2010 ICDVRAT; ISBN 978 07049 15022

Druin, A., Alborzi, H., Boltman, A., Cobb, S., Montemayor, J., Neale, H., Platner, M., Porteous, J., Sherman, L., Simsarian, K., Stanton, D., Sundblad, Y and Taxen, G. (2000). Participatory Design with Children: Techniques, Challenges, and Successes. Proceedings of The Participatory Design Conference PDC 2000. City University, New York. ACM Press.

Druin, A., Bederson, B., Boltman, A., Miura, A., Knotts-Callahan and Plat, M. (1999). Children as Our Technology Design Partners. In A Druin (Ed.) *The Design of Children's Technology: How We Design, What We Design and Why*. Morgan Kaufmann Publishers

Edlin-White, R.W. (2009). *Designing Collaborative Systems for Autistic Pupils*. MSc dissertation, University of Nottingham (unpublished)

Fischer, G. and Sullivan, J. (2002). Human-centered public transportation systems for persons with cognitive disabilities – Challenges and insights for participatory design. In *Proceedings of the Participatory Design Conference* (June) Malmö University, Sweden, T. Binder, J. Gregory, and I. Wagner Eds. Palo Alto, CA, 194-198

Garzotto, F. (2008). Broadening children's involvement as design partners: From technology to "experience". In: *Proceedings of IDC 2008*, July 11-13, 2008, Chicago, IL, USA, p186-193.

Grandin, T. (2002, December - last update) Teaching Tips for Children and Adults with Autism. Autism Research Institute. Available: http://www.autism.com/families/therapy/teaching_tips.htm

Hardy, C., Ogden, J., Newman, J. & Cooper, S. (2002) *Autism and ICT: A Guide for Teachers and Parents*. London, UK: David Fulton Publishers Ltd

Lalji, Z. and Good, J. (2008). Designing new technologies for illiterate populations: A study in mobile phone interface design. *Interacting with Computers*, 20, 574-586.

Maguire, M., Elton, E., Osman, Z., and Nicolle, C. (2006). Design of a virtual learning environment for students with special needs. *An Interdisciplinary Journal on Humans in ICT Environments*, 2(1), 119-153.

Millen, L., Edlin-White, R. & Cobb, S.V.C. (2010). The Development of Educational Collaborative Virtual Environments for Children with Autism. Proceedings of the 5th Cambridge Workshop on Universal Access and Assistive Technology, Cambridge 2010. http://www-edc.eng.cam.ac.uk/cwuaat/

Neale, H., Cobb, S. and Kerr, S. (2003). An inclusive design toolbox for development of educational Virtual Environments. Presented at: Include2003, Royal College of Art, London, 25-28 March 2003

Neale, H.R., Cobb, S.V. and Wilson, J.R. (2002). A front-ended approach to the user-centred design of Virtual Environments. IEEEVR 2002, 24th-28th March, 191-198.

Neale, H.R., Cobb, S.V.G, Wilson, J.R. (2001). Involving users with learning disabilities in virtual environment design. In proceedings of Universal Access in HCI, New Orleans, Lawrence Erlbaum Associates, 506-510.

Parsons, S. & Mitchell, P. (2002). The potential of virtual reality in social skills training for people with autistic spectrum disorders. *Journal of Intellectual Disability Research* 46(5):430-443

Patel, H., Sharples, S., Letourneur, S., Johansson, E., Hoffmann, H., Lorisson, J., Saluäär, D., and Stefani, O. (2006b). Practical evaluations of real user company needs for visualisation technologies. *International Journal of Human-Computer Studies*, 64(3), 267-279.

Patel, H., Stefani, O., Sharples, S., Hoffmann, H., Karaseitanidis, I., and Amditis, A. (2006a). Human centred design of 3D interaction devices to control virtual environments. *International Journal of Human-Computer Studies*, 64(3), 207-220.

Scaife, M. and Rogers, Y. (1999). Kids as Informants: Telling us what we didn't know or confirming what we knew already? In: A. Druin (ed) *The Design of Children's Technology*. Morgan Kaufmann Publishers.

Siegel, B. (2003). *Helping children with autism learn: Treatment approaches for parents and professionals*. New York, USA: Oxford University Press Inc.

Wilson, J. R., Patel, H., and Pettitt, M. (2009). Human factors and development of next generation collaborative engineering. In: *Proceedings of the Ergonomics Society Annual Conference*, London, 22-23 April 2009, London: Taylor and Francis.

Wing, L. & Gould, J. (1979). Severe impairments of social interaction and associated abnormalities in children: Epidemiology and classification. *Journal of Autism and Developmental Disorders*, 9(1):11-29

Wing, L. (1996). Autistic spectrum disorder. *British Medical Journal* 312: 327-328

Worth, S. (2005). *Autistic spectrum disorders.* London: Continuum.

©2010 ICDVRAT; ISBN 978 07049 15022

Post-traumatic stress disorder treatment with virtual reality exposure for criminal violence: a case study in assault with violence

A De la Rosa-Gómez, G Cárdenas-López

Virtual teaching and Cyberpsychology Laboratory, National Autonomous University of Mexico
Av. Universidad 3004, Col. Copilco-Universidad, Mexico City, MEXICO

anabel.dlr@gmail.com, cardenas.georgina@gmail.com

www.ciberpsicologia.psicol.unam.mx

ABSTRACT

The criminal violence is attached with mental health problems as depression and substance use and abuse. However one of most important psychological problems linked with the victims of violence is post traumatic stress disorder (PSTD). In Mexico, according to the ENSI-5 in 2009, 11% (6,800/for each 100 thousands of habitants) of the population over 18 years, experienced a crime. One in four of the people victim of violence develops PSTD symptoms. Due to this socially relevant problem and based on the efficacy treatments, it is important to design treatments involving the use of Virtual Reality (VR), because it can help overcome some of the limitations of traditional therapy using exposure. The present paper expounds a case study of treatment program to PTSD in assault with violence.

1. INTRODUCTION

Violence is an issue of great importance for the general population, because of their health and economic implications. Assaults in the public streets create an atmosphere of danger and vulnerability. According to the World Health Organization (WHO, 2002), violence has important implications; both psychologically and physically, among the consequences of violence are depression, alcohol use and substance abuse. The most important psychological difficulties experienced by victims, are post-traumatic stress disorder (PTSD).

In Mexico, according to data reported by the National Survey on Insecurity (ICESI, 2009) reported that 11% (6,800 / per 100 thousand inhabitants) of the population over 18 years old was victim of a crime. Over these cases, 1 in 4 had PTSD symptoms. The National epidemiologic psychiatric survey (Medina- mora, Borgues, Lara, Ramos, Zambrano & Fleiz, 2005), informed that 5.6% of urban population presents PTSD after suffering kidnapping and 1.8% for robberies or assaults with weapons. Contemplating this background, it is important to note the great impact of violence on mental health. It is remarkable that PTSD requires attention because who suffers from this disorder has elevated degrees of anxiety, fear and avoidance, could be presented in different ways that interferes in the personal development and everyday life of persons.

People who experience an assault start to show psychological and physiological responses as a result of the threat to their personal integrity. They suffer the risk of loosing theirs life or physical injuries. Posttraumatic adaptation is the result of the interaction of multiple variables (Williams & Yule, 1997). Some of these variables are the appreciation and appraisal of the incident, the characteristics and consequences of the aggression and the coping skills of each individual (Carvajal, 2002; Harvey, 1999). Medical assistance, hospitalization, invasive treatments and rehabilitation produces variations in the emotional response on the individual (Michaels, Smith, Moon, Peterson & Long, 1999).

A psychological consequence after being in a threatening incident not only depends in the intensity and characteristics of the situation but also in the differences between individuals; such as: age, background violent experiences, emotional stability, psychological resources, self-esteem, social and familiar support among others. For this reason risk and protector factor are important issues in order to understand the psychological consequences of traumatic events (Echerburúa, Amor & Corral, 2005).

The Posttraumatic stress disorder (DSM-IV-TR, 2000) appears when the person experience or witness a physiological injure or incident that threaten their life or the life of other person. Enclosed with the situation

©2010 ICDVRAT; ISBN 978 07049 15022

they feel an intense fear, horror and defenseless. There are three important aspects for the clinic diagnostic of PTSD: a) intrusive thoughts and constant involuntary flashbacks of the traumatic event; b) cognitive and behavior avoidance of places and situations related with traumatic incident; and c) hyper activation responses such as concentration problems, irritability and sleeping disturbance (Rothbaum y Foa, 1996). Nowadays there are effective cognitive-behavior (CBT) treatments for PTSD. These treatments employ exposure techniques that help patients to overcome the presence of feared objects or situations related with the traumatic event. Prolonged exposure (PE) is the exposure technique preferred for treating PTSD (Foa, Friedman & Keane, 2000). However this technique is poorly used in clinic treatments (Becker, Zayfert & Anderson, 2004). The lowest used of these treatments is due to cognitive avoidance of patients to recall traumatic memories and the difficulty for some patients to imagined (Botella et al, 2006).

Virtual reality exposure technique (VR) can help to overcome some restrictions of traditional exposure therapy (in vivo or imagined). VR can simulate the traumatic situation with a high sense of reality; therefore this can help patients no matter its ability for imagined. Other benefit is that therapists can control the characteristics of the situation presented to the patient. These aspects could reduce cognitive avoidance in order to increase the emotional implication during exposure. This innovating treatment implies high benefits; easy procedures and recent studies reported effectiveness in treating anxiety disorders, eating disorders, addictions, pain management, palliative care and rehabilitation (Rizzo, 2006).

2. METHOD

2.1 Objective

Determinate the effects of virtual reality exposure in PTSD treatment program for criminal violence victims.

2.2 Participant

The participant is a 22 years old, young man, who covered the DSM-IV criteria for posttraumatic stress disorder, types I, for assault with violence and accepted under informed consent to participate in research. He reported had suffered five months ago an assault with violence and death threats by an intoxicated man. As a result, the patient experiences anxiety levels to talk to unfamiliar people or strangers. The participant, reliving the event in the form of repeated and uncontrollable memories through nightmares, which presents anguish, as well as psychological distress, fear to repeat the incident and also by the presence of avoidance behavior, such as not going out alone at night, not pass on alone sites, in addition, to avoid violence programs or discussions concerning the traumatic memory. He showed symptoms of anxiety (physiological arousal), sweating, rapid heart rate and trembling at the memory of the traumatic event or related situations.

2.3 Procedure

A preliminary screening and interview was conducted during which the participant was informed about study details at Psychology Health Center at UNAM. A PTSD diagnosis was determinate by clinician Administrated PTSD Scale (CAPS-1; Blake et al., 1990; Palacios, 2002), PTSD check list, The PTSD symptom Scale Self Report (PSS; Foa, Riggs, Dancu & Rothbaum, 1987; Almanza et al., 1996), The Beck Depression Inventory (BDI, Beck, et al., 1961; Jurado et al., 1998), The State-Trait Anxiety inventory (STAI, Spielberger, 1983; Spielberger & Díaz-Guerrero, 1975) and Quality of Life Inventory (INCAVISA, Sanchez-Sosa, et al., 2009).

2.4 *Treatment*

Treatment was delivered in 10, 90- minute individual sessions conducted once weekly (Rothbaum, Difede & Rizzo, 2008). In session 1, the participant received information about the treatment rationale, education around common reactions about trauma, and breathing relaxation training. Session 2, was focused in traumatic memory. This was explained in the education context about exposure therapy as a medium to confront feared memories and processing the memory. Session 3, consisted to construct a hierarchy of situations or activities and places the participant was avoided, in order to assigning specific in vivo exposures for homework. Session 4- 9 consisted of repetition of the traumatic memory with VR exposure. Subjective Units of Distress (SUDS) ratings ranging from 0 to 10 were asked to the patient every 5 minutes during the exposure. Session 10, was a final session, includes discussion about the continued practice of all that the patient was learned in treatment.

©2010 ICDVRAT; ISBN 978 07049 15022

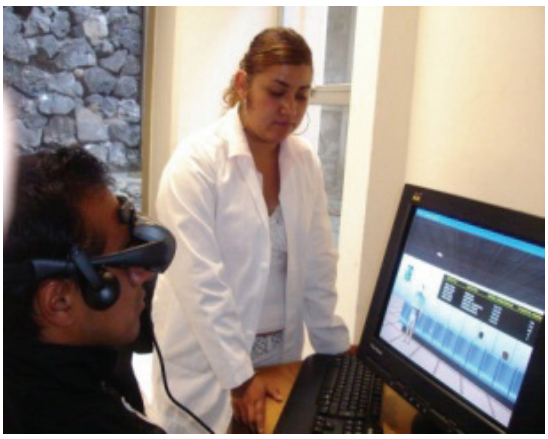


Figure 1. *The VR-system provides confidence to the patient to learn that the virtual environment is handled by the therapist through a keyboard or electronic panel that ensures total control of exposure in real time.*

2.5 Materials

- PC Pentium III (1000KHZ, 256 MB , CD-ROM drive y graphic board AGP, 64 MB, by Open GL.
- Head mounted display (HDM)
- Mouse, board, earphones, loudspeakers
- Microsoft Windows Software (95, 98, ME, 2000 o NT 4.0.)

2.6 PTSD Scenario Settings

Was used 2 virtual developments for PTSD, which are dynamic graphical environments and three-dimensional (3D), Studio Max, high acoustical and tactile, modeled through a computer-oriented simulation of situations or real world variables. The PTSD scenario settings (Cárdenas, 2009) were a streets of Mexico City scenario, which includes a pedestrian bridge, and a vehicle (taxi / wagon), with the aim of exposing the patient to the memories of the trauma. In order to achieve the immersion of the participant, each scenario is navigable and interactive. Note that virtual environments are designed, considering the social and cultural context appropriate for the target users of the system.

Streets of Mexico City scenario: As a public space, is considered a scenario feared by patients, perceived as an unsafe place, which puts them in a vulnerable situation of assault or kidnapping. Through this scenario, the user walks freely through the avenue. Maybe incorporated into virtual characters (avatars) look suspicious that approximates the user with different levels of closeness (Fig. 2).

Pedestrian bridge: The model begins in the early part of the stairs of a footbridge, the patient can walk across the bridge up the stairs and walk through the narrow corridors to reach the other side and cross the street, as well alone or with people who obstruct passing through the bridge in order to continue exposing and confronting the patient to feared places and catastrophic ideas about going out and doing daily activities (Fig. 3).

A vehicle (taxi / wagon): This scenario represents one of the most feared by people who have been victims of assault. The user is confronted with elements of discomfort or anxiety triggers, such as victimization by the driver and interception of other frightening characters, which together with other associated stimuli, such as streets closed path, lighting the stage, will allow you to recreate the feared situation (Fig. 4).

©2010 ICDVRAT; ISBN 978 07049 15022

Figure 2. *City view.*

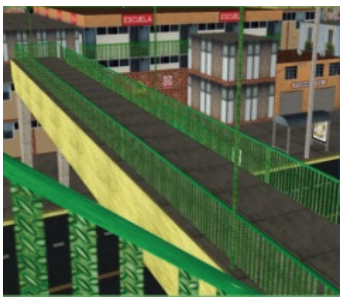


Figure 3. *Bridge view.*

Figure 4. *Taxi view.*

3. RESULTS

The participant's clinical levels of PTSD and Depression significantly reduced and his level of anxiety measurable reduced from his pre-treatment assessment to post-treatment assessment were showed in table 1. Specifically, at the end of 10 sessions of VR program treatment, The CAPS score decrease by 51 % from total score (81). The PTSD symptom Scale ratings decreased from 35 to 20. The participant was assessed at the end of the treatment, and not meeting the DSM-IV criteria for PTSD.

Table 1. *Pretreatment to Post-treatment Assessment ratings*

Measure	Pretreatment	Post -treatment
CAPS total	81	40
CAPS Reexperiencing	20	8
CAPS Avoidance	37	10
CAPS Hyperarousal	24	16
PTSD symptom Scale	35	20
BDI	16	5
STAI	47	25

Table 3. *SUDS ratings (1-10): In Vivo Exposure Hierarchy*

Task	SUDS Sessio3	SUDS session4	SUDS session5	SUDS session6	SUDS session7	SUDS session8	SUDS session9	SUDS session10
Taking public transportation	7	5	5	5	4	4	3	3
Talking to strangers	8	6	5	4	5	3	3	3
Watching movies that has some violence	6	7	6	4	4	4	3	3
Being watching or touching by someone	7	7	6	5	5	5	4	3

Table 3 showed significant changes to reduce levels of anxiety through in vivo exposure for homework during treatment program. Anxiety reduction was showed during sessions by decreased level of reexperiencing, avoidance and hyperarousal ratings. The SUDS rating progressively decrease within sessions (Table 2).

©2010 ICDVRAT; ISBN 978 07049 15022

Table 2. *Subjective Units of Distress (SUDS) rating (1 -10) during Virtual Reality Exposure sessions*

Session Number	Beginning	5 min.	10 min.	15 min.	20 min.	25 min.	30 min.
4	8	6	7	8	7	5	4
6	9	7	7	8	6	4	4
8	7	6	7	6	6	5	4
10	5	4	3	4	4	4	4

4. CONCLUSIONS

According with obtained results, the prolonged exposure treatment with virtual reality was effective in reducing symptoms of reexperiencing, avoidance and hyperarousal. The participant reported feeling comfortable with technology. In addition, He reported experiencing improvement in functioning in many areas of his life as a result of treatment.

The combination of new technologies for psychological treatment seems to be a promising alternative for the care of PTSD in victims of criminal violence, which have great impact on our country, supporting the spread of empirically validated treatments in the Mexican mental health field. However, PTSD treatment program with virtual reality in criminal violence is recommended to test with a larger sample and in a randomized controlled trial with another experimental condition to compare the results.

5. REFERENCES

Almanza, JJ., Páez, F., Hernández, M., Barajas, G., Nicolini, H. (1996). Traducción, confiabilidad y validez concurrente de dos escalas del trastorno por estrés postraumático. *Salud mental V*., suppl 19:2-4.

Becker, C.B., Zayfert,C., y Anderson,E. (2004) A survey of psychologists' attitudes towards and utilization of exposure therapy for PTSD. *Behaviour Research and Therapy*, 42: 277–292

Blake, D., Weathers, F. & Nagy, D. (1990). A clinical administered PTSD scale for assessing current and lifetime PTSD: the CAPS-I. Behavioral Therapy; 18:187-8.

Botella, C., Baños., R., García-Palacios, A., Quero, S., Guillén, V., Marco, H. (2006). La utilización de las nuevas tecnologías de la información y la comunicación en Psicología clínica. *Revista sobre la sociedad del conocimiento*; 004, 34-41.

Cárdenas, G. (2009). Desarrollo de Ambientes virtuales para el trastorno por estrés postraumático. Facultad de Psicología. UNAM.

Carvajal, C. (2002). Trastorno por estrés postraumático: aspectos clínicos. *Revista Chilena Neuro-Psiquiátrica*; 40 (supl 2): 20-34.

De la Fuente, R. & Medina-Mora, ME. (1987). Las adicciones en México. I. El abuso del alcohol y los problemas relacionados. *Salud Mental*; 10 (2), 3-13.

Echerburúa, E., Amor, P., Corral, P., 2005. En V. E. Caballo (dir.) *Manual para la evaluación clínica de los trastornos Psicológicos*. Madrid*:* Pirámide.

Foa, EB., Keane, TM. & Friedman, MJ. (2000). *Effective Treatment for PTSD, Practice Guidelines for the International Society for Traumatic Stress Studies*. Nueva York: Guilford Press.

Instituto Ciudadano de Estudios sobre la Inseguridad, A.C. (ICESI). (2009). La percepción de inseguridad en las principales regiones urbanas de México. Gaceta Informativa. Disponible en: www.icesi.org.mx.

Medina- Mora, M.E., Borgues, G., Lara, C., Ramos, L., Zambrano, J. & Fleiz, C. (2005). Prevalencia de sucesos violentos y de Trastorno por Estrés Postraumático en Población Mexicana. Resultados de la encuesta nacional de epidemiología psiquiátrica en México. Instituto Nacional de Salud Pública. *Salud Mental*; 47, 001.

Michaels, AJ., Michaels CE., Smith, JS., Moon, CH., Peterson, C. & Long, WB. (1999). Posttraumatic Stress Disorder in injured adults: etiology by path analysis. *Journal of Trauma*; 47: 867-73.

Rizzo, A. (2006). State of the Art in Virtual Rehabilitation. *CyberPsychology & Behavio*r; 9 (2). 113.

©2010 ICDVRAT; ISBN 978 07049 15022

Rosovsky H., Borges G. (1996). Consumo *per cápita* de alcohol en México (1979- 1994) y sus correcciones con datos de las encuestas poblacionales. Trabajo presentado durante la reunión: "Alcoholismo" CONADIC, México.

Rothbaum, B.O., & Foa, E.B. (1996). Cognitive-behavioral therapy for posttraumatic stress disorder. En B.A. Van der Kolk, A.C. McFarlane y L. Weisaeth. (Eds). *Traumatic stress: The effects of over-whelming experience on mind, body, and society*. New York. Guilford Press.

Rothbaum, B.O., Difede J. & Rizzo, A. (2008). Therapist treatment manual for virtual reality exposure therapy. Virtually Better. Virtual Iraq treatment Manual.

Spielberger, D. y Díaz-Guerrero, R. (1975). *Inventario de ansiedad rasgo-estado. México*: El Manual Moderno.

Williams, J. & Yule, W. (1997). *Understanding post - traumatic stress. A psychosocial perspective on PTSD and treatment.* New York: John Wiley & Sons.

World Health Organization. (2001). *Composite International Diagnostic Interview (CIDI) version 15*. Ginebra, Suiza: WHO.

©2010 ICDVRAT; ISBN 978 07049 15022

Telehealth using 3D virtual environments in stroke rehabilitation – work in progress

J Broeren[1,3,4], L Pareto[2], C Ljungberg[2], B Johansson[1], KS Sunnerhagen[3], M Rydmark[4]

[1]Department of Research and Development, NU-Hospital Organisation,
SE-451 85 Trollhättan/Uddevalla, SWEDEN

[2]Laboratory of Interaction Technology, University West,
SE-461 86 Trollhättan, SWEDEN

[3]Institute of Neuroscience and Physiology, University of Gothenburg,
SU/Sahlgrenska, SE-413 45 Göteborg SWEDEN

[4]Institute of Biomedicine, Mednet, University of Gothenburg,

Box 420, 405 30 Göteborg SWEDEN

[1]*jurgen.broeren@mednet.gu.se*, [2]*lena.pareto@hv.se,* [2]*christer.ljungberg@hv.se,*
[3]*ks.sunnerhagen@neuro.gu.se,* [4]*martin.rydmark@mednet.gu.se*

[1]*www.nusjukvarden.se,* [2]*www.hv.se,* [3]*www.neurophys.gu.se,* [4]*www.mednet.gu.se*

ABSTRACT

We have now started testing a telehealth system for stroke rehabilitation in a rural area in Sweden (NU- Hospital Group Area). For collection of assessments and audiovisual communication, the telehealth system has bidirectional contact with the home-based units. To date, three stroke subjects' participated; they were instructed to play 3D computer games with the hemiplegic upper extremity. The intervention led to clinical changes for all subjects. The analysis of the audiovisual communication revealed that the both stroke subjects and therapists were not yet effective in regulating their turn taking process. The data suggests the feasibility of a distance based approach using 3D virtual environments for upper extremity rehabilitation after stroke.

1. INTRODUCTION

Rehabilitation aims to improve function, i.e. guide subjects with stroke to reenter the community true active involvement so they can become as independent as possible (Barnes 2003). Hospital Rehabilitation of stroke subjects starts in the acute phase, then when the stroke is no longer immediately life-threatening, the rehabilitation continues in inpatient, home-care, and/or outpatient settings (Adams et al. 2003). During the inpatient setting, the training may consist of getting out of bed, eating and drinking, dressing, bathing, cooking, and toileting (Duncan et al. 2005). These activities subsequently expand to train the ability to handle independence. Once at home, training continues in to enable stroke subjects to return to their normal abilities - day-to-day tasks, such as managing domestic tasks.

Home-based health care is considered cost-effective, and has shown examples which are as successful as hospital-based rehabilitation programs. Surveillance of such programs is normally conducted via telephone interviews or home visits. The prevailing thought is that home visits holds an advantage over telephonic interventions because of the face-to-face contact with subjects, for instance answers have shown to be significantly more reliable (Linden 2006).

This project addresses two major problems within stroke rehabilitation. Firstly, it is a common problem that many subjects with stroke find the daily exercises that they are to perform at home are not very interesting and thereby lose motivation when they return home from the hospital. The second problem is that current methods require subjects with stroke to return to the hospital on a frequent basis for rehabilitation and to be monitored by hospital staff. Traveling to and from the hospital frequently poses, a large cost to hospitals. Our approach is a combination of the two: 3D- computer gaming and follow-up online meetings with audiovisual computer-mediated communications tools.

©2010 ICDVRAT; ISBN 978 07049 15022

2. METHODS

2.1 Subjects

Three male subjects were invited to participate in a telehealth care program for stroke rehabilitation. Three subjects were included in this study where referred to an outpatient clinic located in Uddevalla, Sweden (Table 1). All the subjects were living in the community in their own homes and were retired. They were referred from an occupational therapist from that primary care clinic and the referral criteria was 1) diagnosis of stroke; 2) hem paresis in one of the upper extremities, that is, box and blocks score lower than 45 (Mathiowetz et al. 1985); 3) no signs of neglect; and 4) a minimum age of 70 years. Exclusion criteria for all subjects were 1) joint problems or prior injury to arm/hand; 2) language difficulty that affects information reception.

The study was approved by The Regional Ethical Review Board in Gothenburg, Sweden and was conducted according to the Helsinki Declaration. All subjects included in the study gave written informed consent.

Table 1. *Stroke subjects characteristics at admission.*

	Age (Years)	Sex	Months since stroke	Side of stroke	Etiology	Intervention period (days)
S1	87	Male	3	Left	Infarct	87
S2	84	Male	10	Right	Infarct	143
S3	78	Male	6	Left	Infarct	121

2.2 Intervention

The intervention used a pre-/post-test design. The scenario is that the user sits at home in front of a computer monitor with stereoscopic 3D visualization and holds a haptic stick (a robotic arm with a track stick, which mediates a feeling of touch and force feedback) with which he/she performs different "serious games". After the set up was installed in the homes, the subjects' were instructed to play 3D computer games for at least 20 minutes a day during the intervention period. At specific hours an occupational therapist monitored and coached the subjects from a distance. Prior to entering the study, the subjects were trained to utilize the telehealth system. For collection of assessments and audiovisual communication between therapists and subjects, the telehealth system had bidirectional contact with the home-based units. If an Internet connection was available in their homes this was used instead of the mobile internet connection.

2.2.1 System Components and Connections (Fig. 1). The system consists of a desktop-sized immersive workbench (www.curictus.com), which uses a three-dimensional (3D) virtual environment with games with an inbuilt rehabilitation component (serious games) designed for upper extremity (UE) movement therapy, and assessment. A patient care management system (PCMS) enables the transfer of real time system data and log files and maintains an archive of all information. From the management system, clinicians can observe and graph subjects' progress and discuss games to be played by each subject. At this stage we make use of current video conferencing technologies (Adobe connect Pro 7.5), i.e. the video/audio teleconference system was not integrated in the immersive workbench. A separate computer monitor was connected to the workbench with a mobile wireless internet connection, a webcam and headset.

2.3 Outcome Measurement

2.3.1 Rehabilitation. Grippit was used to measure grip force (N) this is a electronic device used clinically that registers force generated by the muscles of the hand (Nordenskiold et al. 1993). The Box and Block Test (BBT) evaluates gross movements of the hand/arm. The test requires moving, one by one, the maximum of blocks from one compartment of a box to another of equal size within 1 min. The Action Research Arm test (ARAT)) assess arm/hand functions using functional activities such as gripping, moving objects or pouring water from one glass to another (Lyle 1981). The EQ5D VAS score was used to assess general health status (Brooks 1996). It records the subject's self-rated health status on a graduated (0–100) scale, with 100 indicating the best health status. We considered a change of 10% as clinically relevant (Alon et al. 2003).

©2010 ICDVRAT; ISBN 978 07049 15022

Figure 1. *Telehealth system: a desktop-sized immersive workbench, PCMS with activity data (velocity graph), and screen shots from the user interface, and video conferences. "Pictures showing subjects are approved for scientific publication by the person in the image"*

2.3.2 Patient Care Management System (PCMS). Automatically stored performance data captured with the PCMS was; 1) results of each game; 2) number of times run ; 3) performance for each run; 4) raw hand movement data, captured at 1000 Hz; 5) game events time stamped to match the raw hand movement data. We administered a UE test developed in a previous study (Broeren et al. 2004). Movement kinematics were measured with the PHANToM Omni® (haptic stylus end-point)) before and after the intervention. From this, time (duration) and distance to complete the test were recorded. From this movement speed, i.e. velocity (m/s) and movement quality (HPR: this is the distance traversed by the haptic stylus, calculating the length of the pathway divided by the straight-line distance to obtain a hand path ratio) were calculated.

2.3.2 Video Conferencing Technology. Conversational Analysis (Riseberg et al. 1997) were used on the recorded meetings as follows: first the conversation was categorized into the topics of a follow-up meeting such as *social talk, health status, planning*, *speech synchronization,* and *technical support*, and the duration was timed. Each topic was labelled as a "type of talk", i.e., instruction, interrogation, confirmation, negotiation or decision, which indicate the strategy used to achieve a goal. Then, for each topic unit, the turn-taking process was analysed and phenomena which decreased fluency of the conversation, such as *talking simultaneously, interrupt partner, disruption in discourse, confused silence*, and *repeating answered question*, was counted.

3. RESULTS

3.1 Rehabilitation Outcome Measurements

The data suggest that the intervention led to clinical changes in grip force (N) for S2 and S3. Manual ability, according to the BBT and ARAT improved for all three subjects (S1-S3). The subjects' self-rated health status (EQ5D VAS score) increased for all three subjects (Table 2).

©2010 ICDVRAT; ISBN 978 07049 15022

TABLE 2. *Rehabilitation outcome measurements for the paretic UE for S1-S3.*

	S1		S2		S3	
	Pre	Post	Pre	Post	Pre	Post
Grippit (N)	244	259	248	315*	26	102*
BBT	40	49*	16	24*	48	56*
ARAT	43	55*	**	38	48	57*
EQ5D VAS score (%)	30	50	30	70	70	90

*clinically significant improvement ≥ 15 %
** no data available

3.2 Patient Care Management System

The plots in Fig. 2 suggest the possibility of linear trends; to be verified in larger scale investigations to come.

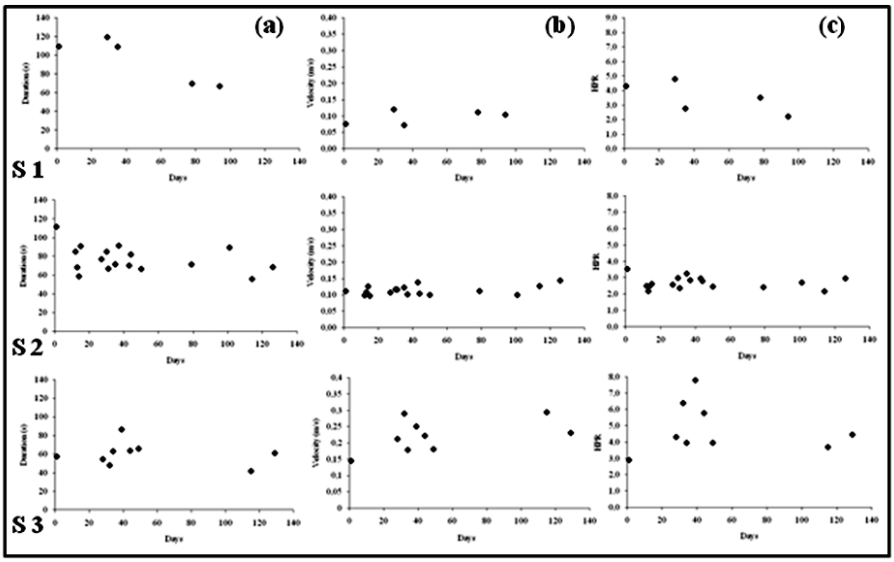


Figure 2. *Kinematic data for the UE test for S1-S3: (a) duration (s), (b) velocity (m/s) and (c) HPR.*

In table 3; the subjects' choice of games (Preferred Game Activity), the amount of each game played and the total time (duration) played during the intervention period.

3.3 Video Conferencing Technology

3.1.1 Technological Problems. A non-reliable internet connection was a problem that made it difficult to have the e-meeting with one subject. The internet connection on the computer was disabled two times and it could not be explained how it could happen. The mobile internet connection used on the therapist computer gave to low bandwidth depending on where the therapist was located. This gave problem with the video and voice transmission and two e-meetings were interrupted and could not be continued. For each of the installations in the subjects' home the system was tested and a brief introduction to the user-interface, web camera and microphone was held with the subject.

To be able to learn how to use the system in a convenient way, training with the therapist on how to use the system was performed when the therapist was visiting in the subjects' home. They were present in different rooms, both using the desktop videoconferencing system and when something failed the therapist could easily help the subject with the difficulties on place. A manual on how to use the system was developed to both the therapist and the subjects' to be at hand when starting up and joining the e-meetings, it was

©2010 ICDVRAT; ISBN 978 07049 15022

distributed at the time of the training. For every e-meeting in the desktop videoconferencing system, a user support person in the e-meeting room was available to help the participants if there were any technical difficulties at that time.

Table 3. *Preferred Game Activity Category for S1-S3 with the amount and duration for each game played*.

SUBJECTS	ACTIVITY	TIMES PLAYED	DURATION (min.)
S1	FISH TANK	34	96
	MATHS	29	108
	MEMORY	159	110
	SPACE TENNIS	42	25
S2	MEMORY	63	60
	FISH TANK	139	313
	MATHS	4	23
S3	FISH TANK	35	62
	LIGHT PUZZLE	2	17
	MATHS	9	17
	MEMORY	95	58
	SPACE TENNIS	29	15
	TARGET BALL	7	88

3.1.2 Conversational Analysis of Online Meetings. Three recorded meetings were analysed, one for each subject. The durations of meetings were approximately 7, 9 and 13 minutes. The first two meetings were mainly therapist-subject conversations (with a short period of technical support in the beginning), whereas the third was an example of a learning situation where the subject was supported by a therapist at his location.

In the Content analysis (Fig. 3) representing relative duration of different topics in the meetings, we have grouped speech synchronization and technical support into one group: communication management, since these are meta-topics of the conversation and are undesirable. Notably, at this early stage of the learning process, communication management activities represent as much as 40-60% of the time. Considering the limited duration of active engagement that is generally possible due to mental fatigue for stroke subjects, it is most important to avoid communication management as much as possible.

In the analysis of the turn-taking process, we found "simultaneously talking" to be the most common obstacle to fluency in the conversation, which is part of the timing management of a dialogue. Simultaneous talk was often a result of one partner trying to take over the speaking role by interrupting during speech or in a short pause, but where the first speaker kept talking. Sometimes simultaneous talk was followed by confused silence and then simultaneous talk again. The disruption of discourse occurred 4-5 times a meeting, and seemed to be a consequence of unclear speaker/listener roles. Such confusion rarely occurs in face-to-face conversations.

©2010 ICDVRAT; ISBN 978 07049 15022

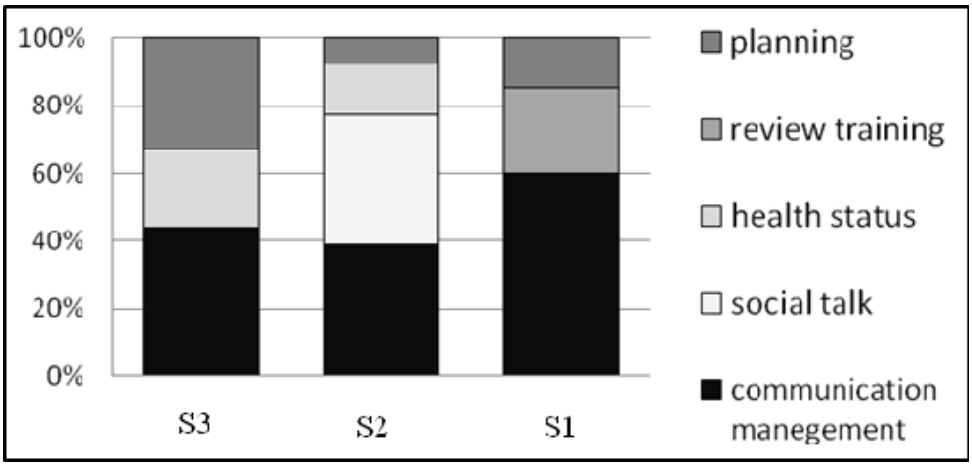


Figure 3. *Content analysis of the e-meetings.*

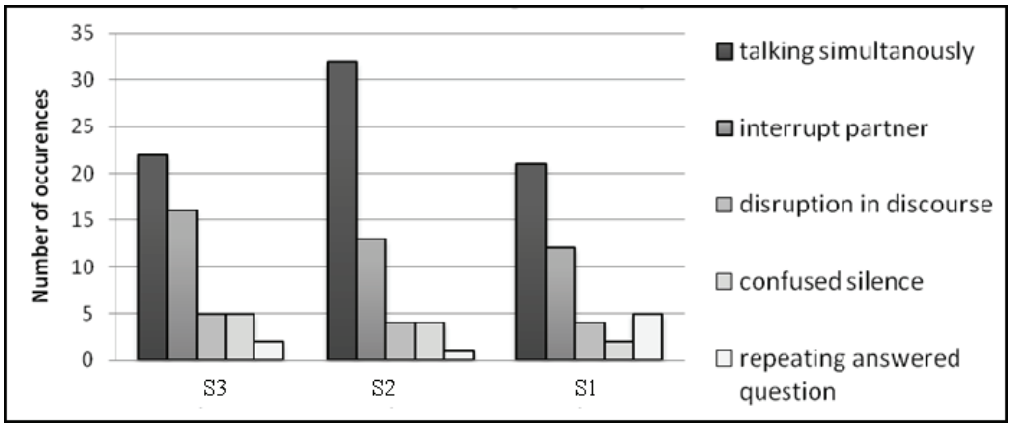


Figure 4. *Phenomena decreasing fluency in conversation.*

4. DISCUSSION

The current proof-of- concept study shows that the purposed telehealth system can be applied to stroke rehabilitation. The subjects' affected upper-extremity impairment improved in the BBT and the movement kinematics delivered by the telehealth system for all subjects (S1-S3). Two subjects in the ARAT (S1 and S3). Grip force of the hand increased for two subjects (S2 and S3). These clinical changes add information to previous studies suggesting the efficacy telehealth (Kairy et al. 2009).

We used an off-the-shelf video-conferencing system to test the feasibility of e-meetings between therapists and subjects, in order to identify requirements and design implications on a future communication tool which will be integrated in the system. It allows thorough analysis of the conversations since meetings can be recorded. Video recordings are particularly appropriate for Conversational Analysis (a sub-method of discourse analysis), since gestures, face expressions and other body language are often highly relevant in social activities such as conversation (Mazur 2004). Conversational analysis using recorded video has previously shown to be effective for deriving design implications (Riseberg et al. 1997).

Communicating via a computer-based medium differ from face-to-face interaction. Aspects of interaction such as noting gaze, gestures and other body language are often highly relevant to interpret conversation (Mazur 2004), and is either absent (as in non-visual media such as chat, e-mail etc) or more difficult to perceive (as in audiovisual media such as video conference systems or video telephone). Such non-verbal cues are to a large extent used to manage conversations, such as turn-taking and synchronizing speaking/listening roles. Moreover, the medium affect the way affective states can be pursued. Non-verbal cues can be interchanged by verbal cues, but is less efficient and need to be learnt (Walther et al. 2005).

Successful rehabilitation is dependent on a stroke subject's motivation and compliance. Earlier studies have shown that the system is motivational and has benefits beyond real life training (Broeren et al. 2008; Pareto et al. 2008). Variation of activities and levels are essential due to subjects' varying abilities and

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

experience. Telehealth can open ways for interactive communication, thus allowing for daily monitoring of progress and adjustments to rehabilitation plans (Broeren et al. 2009). The benefits of using telehealth would be enhancing the quality of stroke rehabilitation with more timely and frequent assessments, as well as greater continuity in the healthcare chain (Winters et al. 2004).

5. CONCLUSIONS

The results of this study indicate that home rehabilitation is a promising approach in remote training and may have beneficial effects on quality of life. Further research is necessary to evaluate clinical efficacy and cost effectiveness with a larger population.

Acknowledgements: This was supported by grants from the NU-Hospital Organisation, the Norrbacka-Eugeniafoundation, and VINNOVA (2008-03956).

6. REFERENCES

H. P. Adams, Jr., R. J. Adams, T. Brott, G. J. del Zoppo, A. Furlan, L. B. Goldstein, R. L. Grubb, R. Higashida, C. Kidwell, T. G. Kwiatkowski, J. R. Marler and G. J. Hademenos (2003), Guidelines for the early management of patients with ischemic stroke: A scientific statement from the Stroke Council of the American Stroke Association, *Stroke,* **34,** *4*, pp. 1056-1083.

G. Alon, K. S. Sunnerhagen, A. C. Geurts and A. Ohry (2003), A home-based, self-administered stimulation program to improve selected hand functions of chronic stroke, *Neurorehabilitation,* **18,** *3*, pp. 215 - 225.

M. P. Barnes (2003), Principles of neurological rehabilitation, *J Neurol Neurosurg Psychiatry,* **74** *4*, pp. iv3-iv7.

J. Broeren, L. Claesson, D. Goude, M. Rydmark and K. S. Sunnerhagen (2008), Virtual rehabilitation in an activity centre for community-dwelling persons with stroke. The possibilities of 3-dimensional computer games, *Cerebrovasc Dis,* **26,** *3*, pp. 289-296.

J. Broeren, M. Rydmark and K. S. Sunnerhagen (2004), Virtual reality and haptics as a training device for movement rehabilitation after stroke: a single-case study, *Arch Phys Med Rehabil,* **85,** *8*, pp. 1247-1250.

J. Broeren, K. Sunnerhagen and R. M. (2009), Haptic Virtual Rehabilitation in Stroke - Transferring Research into Clinical Practice, *Physical Therapy Reviews,* **15,** *5*, pp. 14.

R. Brooks (1996), EuroQol: the current state of play, *Health Policy,* **37,** *1*, pp. 53-72.

P. W. Duncan, R. Zorowitz, B. Bates, J. Y. Choi, J. J. Glasberg, G. D. Graham, R. C. Katz, K. Lamberty and D. Reker (2005), Management of Adult Stroke Rehabilitation Care: a clinical practice guideline, *Stroke,* **36,** *9*, pp. e100-143.

D. Kairy, P. Lehoux, C. Vincent and M. Visintin (2009), A systematic review of clinical outcomes, clinical process, healthcare utilization and costs associated with telerehabilitation, *Disabil Rehabil,* **31,** *6*, pp. 427-447.

A. Linden (2006), Evaluating the Effectiveness of Home Health as a Disease Management Strategy, *Home Health Care Management & Practice,* **18,** *3*, pp. 216-222.

R. C. Lyle (1981), A performance test for assessment of upper limb function in physical rehabilitation treatment and research, *Int J Rehabil Res,* **4,** *4*, pp. 483-492.

V. Mathiowetz, G. Volland, N. Kashman and K. Weber (1985), Adult norms for the Box and Block Test of manual dexterity, *Am J Occup Ther,* **39,** *6*, pp. 386-391.

J. M. Mazur (2004), Conversational analysis for educational technologists: theoretical and methodological issues for researching the structures, processes and meaning of online talk. In *Handbook of research on educational communications and technology*, (D. H. Jonassen, Eds), Lawrence Erlbaum Associates, Mahwah, NJ, pp. 1073-1098.

U. M. Nordenskiold and G. Grimby (1993), Grip force in patients with rheumatoid arthritis and fibromyalgia and in healthy subjects. A study with the Grippit instrument, *Scand J Rheumatol,* **22,** *1*, pp. 14-19.

L. Pareto, D. Goude, M. Rydmark and J. Broeren (2008), Virtual reality, haptics and post-stroke rehabilitation in practical therapy Article in conference, *Proc. 7th International Conference on Disability, Virtual Reality and Associated Technologies with ArtAbilitation 2008*, Porto, Portugal, pp. 245-252.

J. C. Riseberg, R. Berkowitz and L. Cunningham (1997), Action and Reaction: Computer-Mediated Dialogues As a Model for Natural Interfaces, Article in conference, *Proc. 2nd International Conference on Cognitive Technology* Aizu, Japan, pp. 109.

J. B. Walther, S. Pingree, R. P. Hawkins and D. B. Buller (2005), Attributes of interactive online health information systems, *J Med Internet Res,* **7,** *3*, pp. e33.

J. M. Winters and J. M. Winters (2004), A telehomecare model for optimizing rehabilitation outcomes, *Telemed J E Health,* **10,** *2*, pp. 200-212.

©2010 ICDVRAT; ISBN 978 07049 15022

A simple camera tracking virtual reality system for evaluation of wrist range of motion

D Shefer Eini[1,2], N Ratzon[1], A A Rizzo[3], S-C Yeh[3], B Lange[3], B Yaffe[2], A Daich[2], P L Weiss[4], R Kizony[2,4,5]

[1] Department of Occupational Therapy, Stanley Steyer School of Health Professions, Tel-Aviv University, Ramat Aviv, Israel

[2] Chaim Sheba Medical Center, Tel Hashomer, Ramat Gan, Israel

[3] Institute for Creative Technologies, University of Southern California, Marina Del Rey, CA, USA

[4] Department of Occupational Therapy, Faculty of Social Welfare & Health Sciences, University of Haifa, Haifa, Israel

[5]Department of Occupational Therapy, Ono Academic College

didikobi@zahav.net.il, navah@post.tau.ac.il, arizzo@usc.edu, Lange@ict.usc.edu, tamar@research.haifa.ac.il, racheli.kizony@gmail.com

ABSTRACT

Clinicians assess wrist and hand function to identify pathology, monitor effectiveness of treatment, and determine the readiness to return to work and other activities. The goniometer, the conventional evaluation tool used to assess range of motion (ROM), is most suited to the measurement of passive and active joint ROM under conditions that entail static, non-functional movements. Instruments that measure ROM during complex, dynamic tasks may encumber the movement. We have adapted a simple optical tracking device that uses a low-cost webcam to track two diodes, referred to as the Virtual Wrist Tracker (VWT), to assess wrist ROM in 30 subjects, aged 18-65 years; fifteen patients had sustained orthopaedic injuries and 15 were control subjects. ROM was assessed by a standard goniometer and by the VWT under two conditions: visual auditory feedback and auditory pacing feedback. The results of test-retest analysis of control subjects demonstrated good reliability for the VWT during wrist extension and moderate reliability during wrist flexion. High, significant correlations were found between the ROM for wrist extension and flexion as measured by a goniometer and via the VWT in the research group and for wrist extension but not for wrist flexion in the control group. A repeated measures ANOVA mixed design showed no significant differences in wrist extension ROM or in wrist flexion ROM during the performance of the task with visual and auditory feedback versus a task with auditory pacing, nor was there interaction effects between task type and group during extension and flexion. Wrist ROM in either direction increased as the participant progressed from one target rectangle to the next; statistically significant interaction effect was found between ROM in target position and group indicating that the difference between the targets in the control group was significantly different than in the research group. Finally, both groups enjoyed performing the VWT tasks but the control subjects felt greater presence, success and control. The VWT appears to be a reliable and valid tool for assessing wrist ROM during dynamic activities.

1. INTRODUCTION

The wrist is a complex joint which includes a large group of tendons, nerves and blood vessels that enable various movements to occur when performing a task. There are many orthopedic pathologies that can occur in the wrist, the most common of which is a fracture of the distal radius (MacDermid et al., 2003; Larsen & Lauritsen, 1993). Clinicians assess wrist and hand function in order to identify pathology, to monitor the effectiveness of treatment, to determine the readiness to return to work and other daily activities, and to evaluate their permanent partial incapacity in order to help determine eventual financial compensation and/or need for vocational retraining (Fess, 1986; Schulz-Johnson, 1987; Swanson et al., 1983; Dipietro et al., 2003). This evaluation includes measures of range of motion, strength and sensation as well as observations related to the loss of limbs, hypersensitivity and cosmesis. Achievement of these clinical goals is confounded

©2010 ICDVRAT; ISBN 978 07049 15022

by the questionable reliability and validity of some of the clinical measures as well as their limitations as dynamic kinematic tools (Weiss et al., 1994).

The goniometer, a metal or plastic protractor-like instrument, is the conventional evaluation tool used to measure range of motion (ROM) of the injured wrist. Specific guidelines, developed by the American Academy of Orthopedic Surgeons and the American Society of Hand Therapists, have identified the required placement of the goniometer as well as the correct position of the upper extremity during ROM measurements. Provided that these guidelines are followed, most researchers agree that goniometric measures of joint range of motion are valid and reliable (Hamilton and Lachenbruch, 1969; Stratford et al., 1984; Gadjdosk and Bohannon, 1987).

Goniometry is most suited to the measurement of passive and active joint range of motion under conditions that entail static, non-functional movements. These are clearly important limitations since the upper extremity engages primarily in complex, dynamic tasks. Moreover, patients, aware of the significance of the hand and wrist assessment, may generate less than their actual active range of motion thereby protracting the time spent in therapy, the days away from work and the cost in compensation.

Over the years a number of alternate methods have been proposed to replace the goniometer for the measurement of wrist range of motion. These include electrogoniometers (Rawes et al., 1996), exoskeleton type apparatus, and glove-based devices (Dipietro et al., 2003). These methods overcome the limitation of static ROM measures but have other drawbacks including encumbrance and difficulty in aligning the sensor to the joint axis (Weiss et al., 1994). An alternate class of instruments is marker-based video tracking (Rab et al., 2002; van Andel, 2008) which do not encumber the subject's limb and are usually more accurate in identifying axes of rotation (Moeslund et al., 2006).

There is a need for tools that measure functional activity and participation as well as support interventions that motivate patients to engage in repetitive practice. The aim is to assess an individual's functional ability in a natural context which takes into account environmental demands while implementing dynamic assessment of hand and wrist function. Virtual reality (VR) is a natural choice as a means of achieving all these aims while supporting an accurate and reliable evaluation of performance similar to the real world (Rizzo and Kim, 2005). In addition, VR technology can improve the consistency and relevance of assessment to the individual's daily life. Given the financial and technical constraints in most clinical settings, the use of simple, low-cost VR technologies is desirable.

A simple, camera tracking VR system was developed by Yeh and Rizzo from the Institute of Creative Technologies at the University of Southern California (Yeh et al., 2008). It is an optical tracking device that utilizes low-cost dual webcams to track with two diodes providing information of six degrees of freedom with a sampling rate of 60 Hz. In the current study, a single camera was used to evaluate planar motion. The participants grasp the hand-held LED, shown in Fig. 1, while viewing the vertical and horizontal motion of a virtual airplane. The task is to steer the airplane through rectangular frames of various sizes and heights in the virtual environment. In order to perform this task, the participants were asked to grasp the grey part of the LED unit with their fingers and flex and extend their wrists. The system provides information regarding the number of successful tracking motions and the motion of the optical device i.e., flexion and extension of the wrist in space.

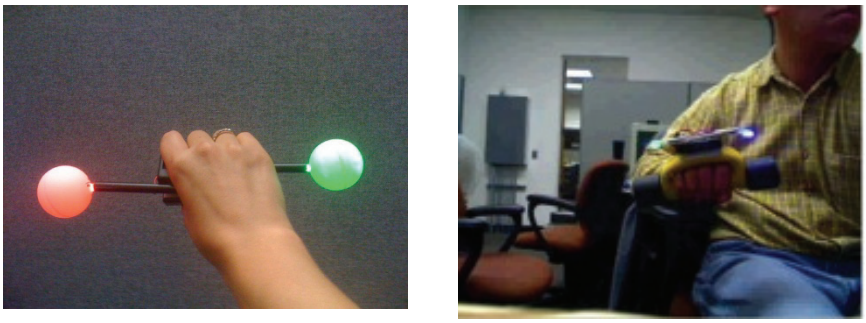


Figure 1. *An optical tracking device that utilizes one or two low-cost webcams to track one, two or three diodes providing information of three, five, or six degrees of freedom, developed by Yeh et al. (2008).*

An initial study of the optical tracking device compared its utility relative to Ascension's Flock of Birds (*http://www.ascension-tech.com/realtime/RTflockofBIRDS.php*) six degrees-of-freedom magnetic tracking system (Yeh et al., 2008). Both the optical and magnetic tracking devices scored highly in the user perception questionnaire and the optical tracker performed as well as magnetic tracking system for game tasks requiring motion within three degrees of freedom and. However, participants were slower completing game tasks

©2010 ICDVRAT; ISBN 978 07049 15022

requiring motion within six degrees of freedom when using the optical tracker; they took a longer time and had more difficulty in completing tasks with motion in the sagittal plane when using the optical tracker. Thus, the low-cost and technically simple optical tracking device appears to be suitable for functional tasks that are not too complex.

The overall goal of the current study was to investigate the usability of the Virtual Wrist Tracker (VWT), an adapted version of Yeh et al.'s (2008) optical tracking device, as a dynamic, clinical measurement tool of wrist movement. This goal was achieved by exploring five objectives:

1. To adapt the original device to meet the ergonomic criteria needed to perform clinical assessment or patients with orthopaedic injury.
2. To determine the test-retest reliability of the VWT system.
3. To compare ROM measured via a goniometer to that measured via the VWT.
4. To determine the discriminant validity of the VWT by comparing differences in range of motion between a group that has sustained a wrist injury and a control group without upper limb injuries.
5. To compare the ROM of the wrist using the VWT to guide performance of tasks with different types of feedback interactivity within a virtual environment.

2. METHODS

2.1 Participants

The research group included 15 adult participants with wrist fractures who were referred to occupational therapy specialists in hand rehabilitation at the Sheba Medical Center, Israel, during a five month period in 2009. Eight participants had wrist fractures of their right hand (53.3%), and seven had fractures of their left hand (46.7%). Nine of the participants had surgery to repair the fracture (60%). The control group included 15 healthy participants who were matched to the research group for age, gender, dominant hand and profession (Table 1).

2.2 Virtual Wrist Tracker (VWT)

Yeh et al.'s (2008) optical tracking device was adapted to improve the hand grip and to provide support for the forearm (Fig. 2). These adaptations were carried out by an occupational therapist and mechanical engineering to comply with ergonomic criteria while maintaining the biomechanical alignment of the device. In the current setup, a single web camera was used, positioned to capture sagittal plane motion (wrist flexion and extension). A close-up view of the tracking device with its dual LEDs is shown in Fig. 3.

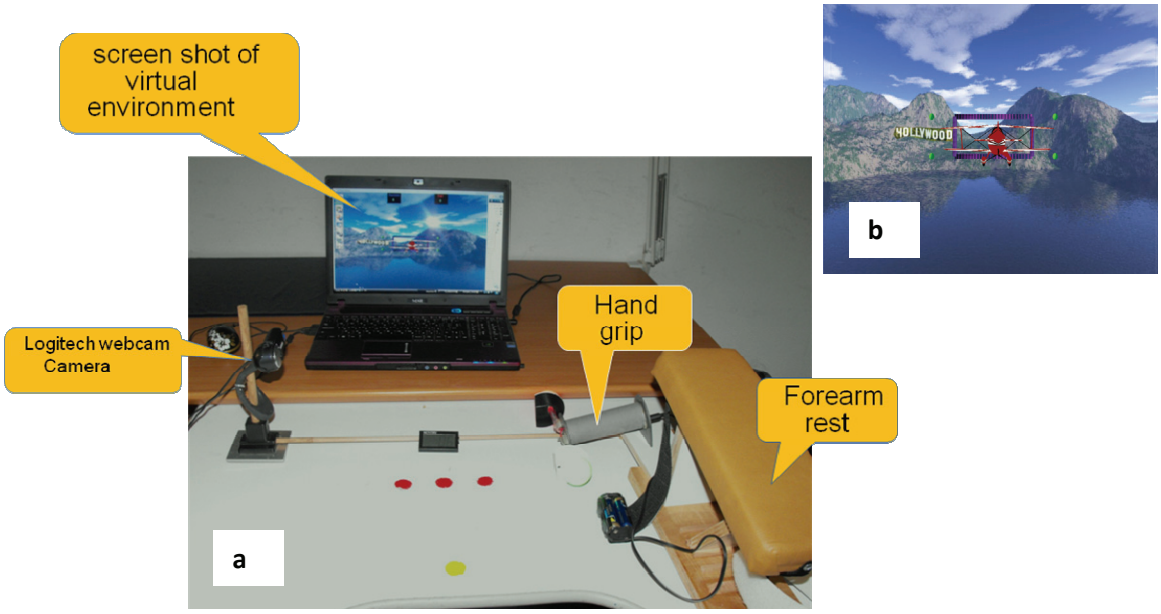


Figure 2. *(a) Experimental setup of the adapted hand-held LED unit with hand grip, forearm rest support, web camera positioned to record motion in sagittal plane and screen shot of virtual environment. (b) enlarged screen shot of the virtual environment showing the airplane and target rectangle.*

©2010 ICDVRAT; ISBN 978 07049 15022

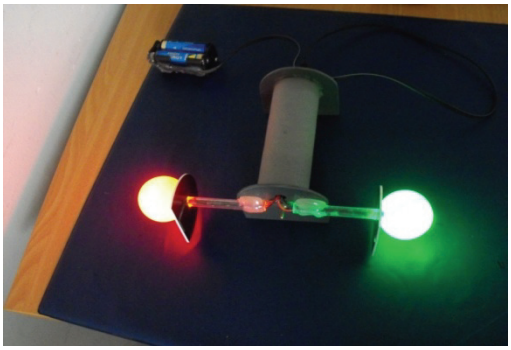


Figure 3. *Hand-held dual LED unit with adapted hand grip.*

2.3 Outcome measures

A demographic questionnaire was used to record participant details including their gender, age, and hand dominance as well as details about their medical condition in the case of the patients. The Functional Status Questionnaire (FSQ) is a 34-item, self administered questionnaire to assess the physical, psychological and social functional status of ambulatory patients (Jette et al., 1986). The Disabilities of the Arm, Shoulder and Hand (DASH) Questionnaire is a 30-item self-report condition-specific questionnaire that measures physical function at the level of disability, evaluating a patient's ability to perform an activity, regardless of how it is done. Lower scores on the DASH reflect less disability and higher scores reflect more disability (McConnell et al., 1999; Beaton et al., 2001). The Short Feedback Questionnaire (SFQ) is a 6-item questionnaire that queries the participant's (1) feeling of enjoyment, (2) sense of being in the environment, (3) success, (4) control, (5) perception of the environment as being realistic and (6) whether the feedback from the computer was understandable (Kizony et al., 2006). Responses to all questions were rated on a 5-point scale, which were combined to give a global response to the experience for a maximum score of 30. An additional question asked whether the participant felt any discomfort during the experience.

Wrist extension and flexion were measured by a standard goniometer and the kinematic output from the VWT was recorded and the maximum flexion and extension ROM of each condition (one with full visual and auditory feedback and one with auditory pacing feedback) and at selected targets (see below) was determined.

2.4 Procedure

Wrist flexion and extension ROM were then assessed with a conventional wrist goniometer. The participants then performed a series of tracking tasks (one each of flexion and extension) while using the VWT VR system under two, counter-balanced conditions. During Condition A (visual and auditory feedback) the participants were able to view the up and down motion of an airplane that they controlled via wrist flexion (down) or extension (up). The magnitude of the ROM was elicited by the position of 15 target rectangles through which the airplane was supposed to pass. The position of successive rectangles was increased to elicit greater ROM as the trial continued. During Condition B (auditory pacing) the participants were requested to perform a similar series of 15 flexion or 15 extension movements but were provided with auditory tempo cues only (the visual display was masked). At the end of each condition, the participants completed the SFQ. The participants' completed the demographic questionnaire, the FSQ, and the DASH at the end of the session. The healthy participants performed two consecutive tests of the visual and auditory feedback condition in order to determine the VWT's test-retest reliability.

2.5 Statistical analysis

SPSS version 17 was used to process the data; the significance level for all of the analyses was set at 0.05. The Intraclass Correlation Coefficient (ICC) was calculated to determine the test-retest reliability of the VWT. Repeated measures mixed design analysis of variance (ANOVA) were calculated to determine differences in wrist flexion and extension ROM between the research and control groups, between the two display conditions and between three target rectangles (i.e. 4th, 9th and 15th target positions).

3. RESULTS

3.1 Participant characteristics

Table 1 shows the participants' demographic, medical and functional characteristics. The mean (SD) age of the research group was 45.0 (15.2) years with 10 males and 5 females. The mean (SD) age of the control

©2010 ICDVRAT; ISBN 978 07049 15022

group was 45.5 (15.7) years with the same gender distribution. Eight of the patients sustained a right wrist fracture and 7 had a left wrist fracture. As expected, the DASH and FSQ scores for the research group indicate a residual disability (DASH) and decreased functional status (FSQ).

Table 1. *Participant demographic, medical and functional characteristic.*

	Research Group (N=15)	Control Group (N=15)
Male:Female	10:5	10:5
Age – mean (SD)	45.0 (15.2)	45.5 (15.7)
Hand dominance (Right:Left)	12:3	12:3
Wrist fracture (Right:Left)	8:7	N/A
Internal fixation (Yes:No)	9:6	N/A
DASH – mean (SD)	45.8 (17.6)	1.9 (1.9)
FSQ – mean (SD)	100.4 (15.6)	129.7 (11.0)

3.2 Test-retest reliability

The ICC was used to determine the test-retest reliability of wrist flexion and extension ROM as measured by the VWT) during two sequential measurements performed by the control group. The results indicate high reliability for wrist extension (r=.924, p=.001,) and moderate reliability for wrist flexion (r=.488, p=.024).

3.3 Validity of wrist ROM

Table 2 shows the means and standard deviations of the wrist flexion and extension ROM of the research and the control groups when measured with a standard goniometer and when recorded during the performance of two conditions, one with full visual and auditory feedback and one with auditory pacing feedback. It is evident that the mean values for the research group are considerably lower than those of the control group for both flexion and extension movements during all three conditions. High, significant correlations were found between the ROM for wrist extension (r=0.641, p<.05) and flexion (r=0.654, p<.01) as measured by a goniometer and via the VWT in the research group and for wrist extension (r=0.761, p<.01) but not for wrist flexion in the control group.

Table 2. *Means and standard deviations of the maximum ROM in the research and control groups for the two VWT conditions.*

Condition	Maximum Range of Motion (degrees)			
	Mean (SD) Flexion		Mean (SD) Extension	
	Research Group	Control Group	Research Group	Control Group
Goniometer	41.0 (10.2)	75.3 (7.2)	36.3 (10.3)	71.0 (8.1)
Condition A (visual & auditory feedback)	56.6 (14.3)	77.8 (6.8)	39.0 (12.7)	70.5 (9.2)
Condition B (auditory pacing feedback)	55.7 (12.0)	82.3 (11.9)	41.6 (14.1)	65.9 (14.5)

A repeated measures mixed design ANOVA was performed to test for differences in wrist extension and flexion ROM between the research and control groups during the two feedback conditions. There was no significant difference in wrist extension ROM during the performance of the task with visual and auditory feedback versus a task with auditory pacing ($F(1,28)=.19$, $p>.05$), nor was there an interaction effect between task type and group ($F(1,28)=2.42$, $p>.05$) (see Fig. 4a). Nor was a significant difference found in the range of motion for wrist flexion during the performance of the visual and auditory feedback task versus the auditory pacing task ($F(1,28)=.64$, $p>.05$); neither was there an interaction between the feedback condition and the group is not statistically significant as well ($F(1,28)=1.45$, $p>.05$) (see Fig. 4b).

The data in Table 3 show the mean maximum range of motion for wrist flexion and wrist extension for both the research and control groups when the participants traversed three of the 15 target rectangles (#4, #9, #15). It is evident that the ROM in either direction increased as the participant progressed from one target rectangle to the next.

Wrist extension ROM during the visual and auditory task at the target rectangles differed significantly for the combined data (both research and control groups) ($F(2,56) = 236.54$, $p<.001$). ROM at target rectangle 4 was significantly smaller than ROM at target rectangle 9 ($F(1,28) = 260.77$, $p<.001$) and ROM at target

©2010 ICDVRAT; ISBN 978 07049 15022

rectangle 9 was significantly smaller than ROM at target rectangle 15 ($F(1,28) = 130.59$, $p<.001$). In addition, ROM of the control group was significantly higher than ROM of the research group ($F(1,28) = 45.56$, $p<.001$) .A statistically significant interaction effect was found between ROM in target position (3 rectangles) and group ($F(2,56)=51.49$, $p<.001$) indicating that the difference between rectangle 4 and 9 and 9 and 15 within the control group was significantly different than in the research group (Fig. 5a).

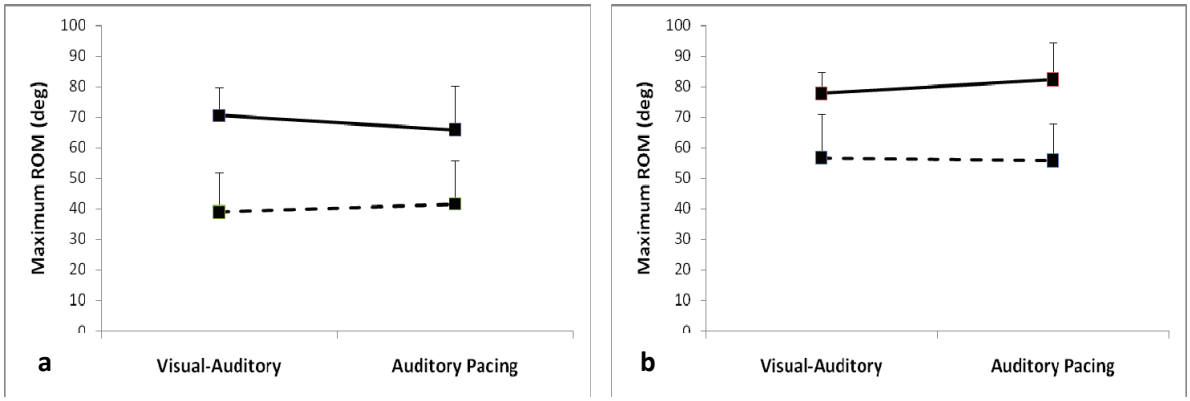


Figure 4. *Mean maximum range of motion with one standard deviation for (a) wrist extension and (b) wrist flexion during the performance of a visual and auditory feedback task versus a auditory pacing task, in the research (dashed line) and the control (solid line) groups.*

Table 3. *Means and standard deviations of the ROM at three different target "rectangles" (4, 9, 15) by the research and control groups*

	Target Rectangle	Range of Motion (degrees) Mean (SD) Flexion		Mean (SD) Extension	
		Research Group	Control Group	Research Group	Control Group
Condition A	4	20.4 (4.4)	21.3 (3.8)	20.7 (3.3)	23.3 (4.6)
	9	43.1 (12.3)	48.3 (4.6)	34.4 (9.3)	47.1 (3.2)
	15	55.5 (14.9)	76.6 (6.3)	38.2 (12.9)	70.5 (9.2)
Condition B	4	26.8 (16.0)	31.6 (24.0)	20.5 (11.0)	23.3 (22.9)
	9	48.7 (13.8)	59.7 (25.7)	36.0 (13.0)	49.5 (19.3)
	15	54.8 (11.8)	81.5 (11.1)	41.1 (14.2)	65.6 (14.4)

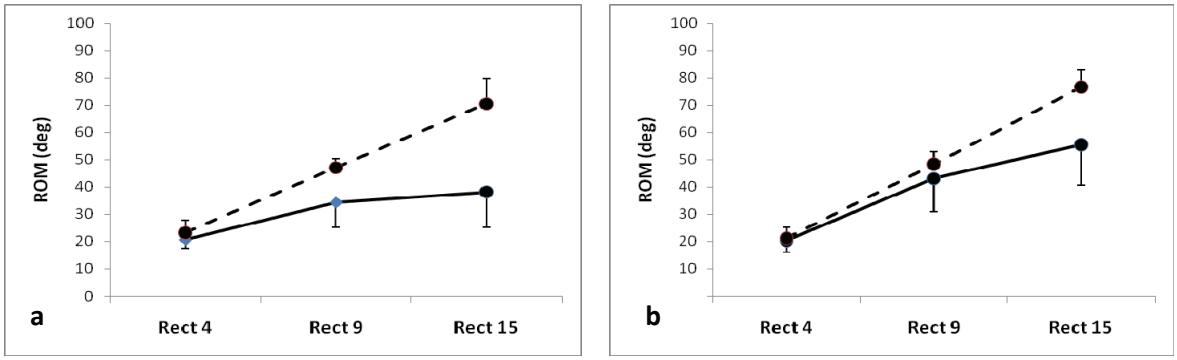


Figure 5. *Maximum range of motion with one standard deviation for (a) wrist extension and (b) wrist flexion at three target rectangles (4^{th}, 9^{th}, 15^{th}) during the performance of the visual and auditory feedback task by the research (solid line) and control (dashed line) groups.*

Results for wrist extension ROM during the auditory pacing task at the target rectangles were similar to those described above for the visual and auditory feedback task with significant differences for the combined data (both research and control groups) ($F(2,56) = 75.00$, $p<.001$). ROM at target rectangle 4 was significantly smaller than ROM at target rectangle 9 ($F(1,28) = 75.39$, $p<.001$) and ROM at target rectangle 9 was significantly smaller than ROM at target rectangle 15 ($F(1,28) = 29.21$, $p<.001$). In addition, ROM of the

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

control group was significantly higher than ROM of the research group ($F(1,28) = 6.96$, $p<.05$) A statistically significant interaction effect was found between ROM in target position (3 rectangles) and group ($F(2,56)= 8.62$, $p<.001$) indicating that the difference between rectangle 4 and 9 and 9 and 15 within the control group was significantly different than in the research group (Fig. 5a).

Wrist flexion ROM during the visual and auditory task at the target rectangles differed significantly for the combined data (both research and control groups) ($F(2,56) = 332.06$, $p<.001$). ROM at target rectangle 4 was significantly smaller than ROM at target rectangle 9 ($F(1,28) = 258.20$, $p<.001$) and ROM at target rectangle 9 was significantly smaller than ROM at target rectangle 15 ($F(1,28) = 171.02$, $p<.001$). In addition, ROM of the control group was significantly higher than ROM of the research group ($F(1,28) = 13.12$, $p<.01$) A statistically significant interaction effect was found between ROM in target position (3 rectangles) and group ($F(2,56)= 18.38$, $p<.001$) indicating that the difference between rectangle 9 and 15 in the control group was significantly different than in the research group (Fig. 5b).

Results for wrist flexion ROM during the auditory pacing task at the target rectangles was similar to that described above for the visual and auditory feedback task with significant differences for the combined data (both research and control groups) ($F(2,56) = 86.12$, $p<.001$). ROM at target rectangle 4 was significantly smaller than ROM at target rectangle 9 ($F(1,28) = 74.63$, $p<.001$) and ROM at target rectangle 9 was significantly smaller than ROM at target rectangle 15 ($F(1,28) = 27.85$, $p<.001$). In addition, ROM of the control group was significantly higher than ROM of the research group for ($F(1,28) = 6.39$, $p<.05$) A statistically significant interaction effect was found between ROM in target position (3 rectangles) and group ($F(2,56)=7.03$, $p<.05$) indicating that the difference between rectangle 9 and 15 in the control group was significantly different than in the research group (Fig. 5b).

3.4 Participant responses to VWT

Participants in both groups reported that they enjoyed the VWT task (mean (SD) SFQ item 1= 3.9 (0.9) for the research group and 3.9 (1.2) for the control group. The control group felt a greater sense of being in the environment (SFQ item 2= 3.5 (1.5)) than did the research group (SFQ item 2= 2.9 (1.4)). They also reported more success during the task (control group SFQ item 3= 4.1 (0.6) versus research group SFQ item 3= 3.1 (0.9)) and a greater sense of control (control group SFQ item 4= 4.4 (0.7) versus research group SFQ item 4= 3.1 (1.1)).

4. CONCLUSIONS

This study was designed to evaluate the usability, reliability and validity of a simple optical tracking device, the Virtual Wrist Tracker, for the clinical assessment of wrist flexion and extension. The VWT demonstrated moderate to good reliability and showed high, significant correlations between the ROM measured by a goniometer and via the VWT. Changes in target rectangle position enable the clinician to evaluate the change in ROM along the task. Both groups enjoyed performing the VWT tasks but the control subjects felt greater presence, success and control. Overall, the VWT appears to be a suitable tool for assessing wrist ROM during dynamic activities.

The results of this study provide support for the use of simple, markerless motion capture device for a variety of clinical applications including the diagnosis and assessment of joint ROM, monitoring of the effectiveness of treatment, determination of the readiness to return to work and other daily activities, and evaluation of permanent incapacity (Fess, 1986).

Future work should examine the ability of such devices to provide treatment for wrist injuries. Considerable evidence has accumulated regarding the use of virtual environments as a means for implementing physical exercises in a game-like setting that is highly motivating for users (Rizzo and Kim, 2005; Rand et al., 2008). However, until recently, environments run on video capture based equipment were either very (e.g., the CAREN VR system *www.motekmedical.com/*) or moderately (e.g., the IREX system *www.gesturetekhealth.com/*) costly. Other options, such as the Sony Playstation II EyeToy, are not readily adaptable to the abilities of people with injuries (Rand et al., 2008) or are only available as customized units. The VWT was constructed with low cost parts and operates with a simple web camera. Yet, it can be easily adapted to provide assessment and training targets. It thus appears to be a tool well suited for routine use in clinical settings.

Acknowledgements: We thank Mr. Paul Drimmer, a volunteer at MILBAT for adapting the hand-held tracking device. We also thank the Dept. of Occupational Therapy at the Sheba Medical Center for providing clinical and research support.

5. REFERENCES

D E Beaton, J N Katz, A H Fossell, et al (2001), Measuring the whole or the parts? Validity, reliability and responsiveness of the Disabilities of the Arm, Shoulder and Hand outcome measure in different regions of the upper extremity, *Journal of Hand Therapy* **14** pp.128–146.

L Dipietro, AM Sabatini, P Dario (2003), Evaluation of an instrumented glove for hand-movement acquisition, *J Rehabil Res Dev*, **40**, pp. 179–190.

F E Fess (1986), The need for reliability and validity in hand assessment instruments, *J Hand Surg*, **11**A: pp. 621-23.

R L Gadjdosk, R W Bohannon (1987), Clinical measurement of range of motion: review of goniometry emphasizing reliability and validity, *Phys Thcr* **67**, pp. 1867-72.

G F Hamilton, P A Lachenbruch (1969), Reliability of goniometry in assessing finger joint angle, *Phys Ther* **67**, pp.1867–72.

A M Jette, A R Davies, P D Cleary, D R Calkins, LV Rubenstein, A Fink, J Kosecoff, R T Young, R H Brook and T L Delbanco (1986), The functional status questionnaire: Reliability and validity when used in primary care, *J Gen Intern Med*, **1**, pp. 143-149.

R Kizony, N Katz, D Rand and P L Weiss (2006), A Short Feedback Questionnaire (SFQ) to enhance client-centered participation in virtual environments, *Proceedings of 11th Annual Cybertherapy Conference: Virtual Healing: Designing Reality.*

C F Larsen and J Lauritsen (1993), Epidemiology of acute wrist trauma, *Int J Epidemiol*, **22**, pp. 911-916.

J C MacDermid, J H Roth, R S Richards (2003), Pain and disability reported in the year following a distal radius fracture: A cohort study, *BMC Musculoskeletal Disorders*,**4**, pp.24-37.

S McConnell, D E Beaton and C Bombardier (1999), The DASH outcome measure user's manual, Toronto: Institute for Work & Health.

T B Moeslund, A Hilton and V Kruger (2006), A survey of advances in vision-based human motion capture and analysis, *Comput Vis Image Und*, **104**, pp. 90-126.

G Rab, K Petuskey and A Bagley (2002), A method for determination of upper extremity kinematics, *Gait Posture,* **15**, pp.113–119.

D Rand, R Kizony and P L Weiss (2008), The Sony PlayStation II EyeToy: Low-cost virtual reality for use in rehabilitation, *Journal of Neurologic Physical Therapy*, **32**, pp. 155–163.

M L Rawes, J B Richardson and J J Dias (1996), A new technique for the assessment of wrist movement using a biaxial flexible electrogoniometer, *J Hand Surg: Journal of the British Society for Surgery of the Hand*, **21**, pp. 600-603.

A A Rizzo and G J Kim (2005), A SWOT analysis of the field of VR rehabilitation and therapy, *Presence-Teleop Virt*, **14**, pp.119-146.

K Schulz-Johnson (1987), Assessment of upper extremity-injured persons' return to work potential, *J Hand Surg*, **12**A, pp. 950-7.

P Stratford, V Agostino, C Brazeau and B A Gowitzke (1984), Reliability of joint angle measurement: a discussion of methodology issues, *Physiother Can*, **36**, pp. 5-9.

A B Swanson, C G Hagert, G Swanson (1983), Evaluation of impairment of hand function, *J Hand Surg*, **8**, pp. 707-22.

P L Weiss, S August, G Peters and J Sampalis (1994), Using the Exos Handmaster to measure digital range of motion: reliability and validity, *Med Eng Phys*, **16**, pp.323–28.

C J van Andel, N Wolterbeek, C A M Doorenbosch, H E J Veeger, and Harlaar (2008), Complete 3D kinematics of upper extremity functional tasks, *Gait Posture*, **27**, pp.120-127.

S-H Yeh, B Lange, C Y Chang, Wang, A A Sawchuk and AA Rizzo, (2008) Effects of Stereoscopic Displays and Interaction Devices on Human Motor Behavior, Proc. of SPIE-IS&T Electronic Imaging, Vol. 6804, 680405-1-10.

©2010 ICDVRAT; ISBN 978 07049 15022

Integrated arm and hand training using adaptive robotics and virtual reality simulations

A S Merians[1], G G Fluet[1], Q Qiu[2], S Saleh[2], I Lafond[2], S V Adamovich[1, 2]

[1]Department of Rehabilitation and Movement Science, University of Medicine and Dentistry of New Jersey, 65 Bergen Street, Newark, NJ, USA

[2,3]Department of Biomedical Engineering, New Jersey Institute of Technology, University Heights, Newark, NJ, USA

[1]*merians@umdnj.edu,* [2]*fluetge@umdnj.edu,* [3]*qq4@njit.edu,* [4]*shs25@njit.edu,* [5]*ial6283@njit.edu,* [6]*adamovich@njit.edu*

ABSTRACT

Virtual Reality simulations interfaced with robotic arm devices are being used for training the upper extremity of people post-stroke. The benefit has been hypothesized to be the ability to provide repetitive task practice, directed visual and auditory feedback, learning algorithms and graded resistive and assistive forces. All of these elements can be manipulated to provide individualized motor learning paradigms. We have developed a unique exercise system, interfaced with complex virtual reality gaming simulations that can train both the upper arm and the hand of people in the chronic phase post-stroke. After two weeks of intensive training, eleven subjects, were able to more effectively control the limb during hand interaction with the target as demonstrated by improved proximal stability, smoothness and efficiency of the movement path. This was in concert with improvement in the distal kinematic measures of fractionation and improved timing. These changes in kinematic measures were accompanied by robust changes in functional tests of upper extremity motor control, the Wolf Motor Function Test, the Jebsen Test of Hand Function and the 9-hole Peg Test.

1. INTRODUCTION

Robotic-assisted arm training devices integrated with strategically placed virtual targets or complex virtual reality gaming simulations are increasingly being used for the rehabilitation of upper extremity deficits post-stroke. Our hypothesis for the use of a virtual reality/robotic system for rehabilitation is that this environment can monitor the specificity and frequency of visual and auditory feedback, and can provide adaptive learning algorithms and graded assistive or resistive forces that can be objectively and systematically manipulated to create individualized motor learning paradigms. It provides an excellent medium for the delivery of repetitive task practice. It has been shown in both animals and humans that neuronal connections are continuously remodeled by experience and that intensive practice of a motor skill leads to an expansion of cortical representations (Merzenich, et al., 1996; Nudo, Milliken, Jenkins, & Merzenich, 1996; Plautz, Milliken, & Nudo, 2000).Congruent with the motor learning and neuroplasticity literature, it is believed that the acquisition of a skill follows a dose–response relationship (Kwakkel, 2006). In rehabilitation, the dose is often measured as the number of task repetitions or practice hours. A major impediment to the delivery of repetitive task practice is the labor intensive nature of these interventions. Multiple authors cite the ability of robotically facilitated training to provide highly repetitious training as a key factor for its effectiveness (Kwakkel, Kollen, & Krebs, 2008; Mehrholz, Platz, Kugler, & Pohl, 2009). The comparison between the training volume typical to robotic interventions and those of traditional UE interventions is marked. Subjects average over 500 repetitions/day in studies in the robotic rehabilitation literature (Aisen, Krebs, Hogan, McDowell, & Volpe, 1997; Aubert, et al., 2005; Dipietro, Krebs, Fasoli, Volpe, & Hogan, 2008) while an observational study of the repetitions performed in a traditional outpatient setting averaged 85 (Lang, MacDonald, & Gnip, 2007). Thus, virtual reality/robotic systems provide a rehabilitation tool that can be used to exploit the nervous systems' capacity for sensorimotor adaptation and provide plasticity-mediated therapies.

Most of these robotic therapies have focused on training the proximal, rather than distal effectors of the upper extremity. This is in keeping with the prevailing clinical paradigm to develop proximal control and mobility of the shoulder prior to initiating training of the hand (Lennon, Ashburn, & Baxter, 2006). However,

©2010 ICDVRAT; ISBN 978 07049 15022

stroke patients report that hand function is the most disabling upper extremity motor deficit. In our past work, we trained the hand alone, with gaming simulations that used relatively simple activities, requiring only control of wrist and finger movement. Neural control mechanisms indicate that arm transport and hand-object interaction are interdependent (Levin, Michaelsen, Cirstea, & Roby-Brami, 2002; Michaelsen, Jacobs, Roby-Brami, & Levin, 2004) suggesting that training on complex tasks that require coordinated effort of both the upper arm and hand may be a more effective method for optimizing recovery of real world hand function (Michaelsen, Luta, Roby-Brami, & Levin, 2001). We have now refined and optimized our system to exercise the hand and the arm together using more complex gaming simulations requiring simultaneous control of integrated shoulder, elbow, forearm, wrist and finger movements. In this paper we report on a study that used multi-faceted interactive gaming simulations and adaptive robots to test the assumption that training the entire upper extremity as a unit will improve hemiparetic hand function of patients post-stroke.

2. METHODS

2.1 Hardware

All simulations in this study utilized CyberGlove© (Immersion) instrumented gloves for hand tracking. A CyberGrasp© (Immersion), a lightweight, force-reflecting exoskeleton that fits over the CyberGlove was used to facilitate individual finger movement in patients with more pronounced deficits (Fig 1). Two of the four simulations use the Flock of Birds (Ascension Technologies) motion sensors for arm tracking and the other two use the Haptic Master robot (Moog FCS Corporation) (Fig 2). Please see (S. V. Adamovich, Fluet, Mathai, et al., 2009; S. V. Adamovich, Fluet, Merians, Mathai, & Qiu, 2009) for full descriptions of the hardware.

2.2 System

Four gaming simulations were developed. They were programmed using either C++/OpenGL or the Virtools software package with the VRPack plug-in (Dassault Systemes). One game was adapted from an existing Pong game in which we transferred the game control from the computer mouse to the CyberGlove and Haptic Master. We used the Haptic Master's Application Programming Interface (API) to program the robot to produce haptic objects, including walls, blocks, cylinders, toruses and spheres as well as haptic effects, such as springs, dampers and global forces. All four simulations integrate components of upper arm movement with wrist and hand movement. In the Plasma Pong game (Fig. 3a), the pong paddle is moved vertically using shoulder flexion/extension while the moving ball is engaged using rapid finger extension. The Hummingbird Hunt simulation depicts a hummingbird as it moves through an environment filled with trees, flowers and a river (Fig.3b) providing practice in the composite movement of arm transport, hand-shaping and grasp. A pincer grip is used to catch and release the bird while it is perched on different objects located on different levels and sections of the workspace. The Hammer Task (Fig. 3c) trains three-dimensional reaching coordinated with repetitive finger flexion/ extension. The subjects reach toward a virtual wooden cylinder, stabilize their upper arm and then use either finger extension or flexion to hammer the cylinders into the floor. The Virtual Piano simulation consists of a complete virtual piano (Fig. 3d) that plays the appropriate notes as they are pressed by the virtual fingers. Please see (Merians, Tunik, & Adamovich, 2009) for full description of the simulations.

2.3 Subjects

Eleven subjects (7 male, 4 female) with a mean (SD) age of 58 (14) years, and a mean (SD) time post stroke of 6 (5) years, participated. Although all subjects met the inclusion criteria of 20° of wrist extension and 10° of finger extension of the hemiplegic hand (Wolf, et al., 2006) there were a range of impairments as shown by the Chedoke McMaster Impairment Inventory stages. The Cheoke McMaster Hand Impairment Inventory stage range was 3-6 and the Chedoke Mcmaster Arm Impairment Inventory stage range was 4-7. Both universities approved the protocol. Subjects trained eight days, on all four simulations during 2-3 hour sessions. Training was divided equally between the four simulations. Because of the intensity of the training and the possible fatigue effect on the hemiplegic shoulder, total training time started on day one at two hours and increased in fifteen minute increments to three hours during Week 1. Training time started and remained at three hours during Week 2.

2.4 Measurement

2.4.1 Kinematic Measures. We have designed the simulation tasks to have both discrete and continuous movements. The secondary measures were the kinematic measures obtained from the two tasks with discrete movements. The Virtual Piano Trainer and the Hammering game are discrete tasks with a definite beginning and end, making them more amendable to kinematic analyses. For the hammer task, maximal extension of

©2010 ICDVRAT; ISBN 978 07049 15022

the metacarpal-phalangeal joints(MCP), duration of the combined transport and hammering phase for each cylinder, the smoothness of the endpoint movement trajectory and the deviation of the endpoint during the hammering were measured. Hand deviation was measured as the mean distance of the hand from the target during hammering (using finger flexion and extension) and is considered a measure of proximal stability and shoulder stabilization during hand-object interaction (Qiu, Fluet, Lafond, Merians, & Adamovich, 2009). For the virtual piano, accuracy, measured by the percent of correct key presses, time to complete the task (duration), and fractionation, which is the ability to isolate the movement of each finger and is measured as the difference in MCP joint angle between the cued finger and the most flexed non-cued finger (S. Adamovich, et al., 2009). For the Hammer Task four separate repeated measures ANOVAs with factor, Measurement Time (Start and End Measures) were used to evaluate changes in arm kinematics (Duration, Hand Path Length, Smoothness and Hand Deviation). For the Piano task, three separate repeated measures ANOVAs with factor, Measurement Time (Start and End Measures) were used to evaluate changes in hand kinematics (Fractionation, Duration, Accuracy).

2.4.2 Clinical Measures. Three timed clinical tests served as clinical outcome measures: Jebsen Test of Hand Function (JTHF) (Jebsen, Taylor, Trieschmann, Trotter, & Howard, 1969), the Wolf Motor Function Test (WMFT) (Wolf, et al., 2005), and the Nine Hole Peg Test (NHPT) (Mathiowetz, Volland, Kashman, & Weber, 1985) . Both the impaired and unimpaired arm/hand were tested for each clinical test. For both the WMFT and the JTHF, a maximum of 120 seconds was recorded when the subject could not perform the subtest (Charles, Wolf, Schneider, & Gordon, 2006). Similar to other reported studies, we eliminated the writing component of the JTHF (Conforto, Cohen, dos Santos, Scaff, & Marie, 2007; Merians, Poizner, Boian, Burdea, & Adamovich, 2006). In each session, the JTHF was administered three times and the mean of the three scores was used for analysis. For the 9-Hole peg test, the worst score in the group was assigned to a subject if they could not perform the test (Daltroy, et al., 1995). Stroke subjects were tested prior to training, immediately post training and at least three months after training. Subjects were at least 6 months post-stroke and reported to be neurologically stable. To confirm the stability of their motor function and absence of confounding spontaneous recovery, for each clinical test, we conducted two baseline tests on a subset (N=7), of the eleven subjects with stroke, two weeks before and one day before the onset of training. In addition, seven age-matched, neurologically healthy subjects were tested on the JTHF, at two week intervals, three times per session. ANOVAs with repeated measures of Measurement Time (Pre-test, Post-test, Retention) were used to evaluate the changes over time in the scores for each of the three timed clinical tests (JTHF, WMFT, NHPT). Finally, preplanned post-hoc comparisons, Pre-test versus Post-test and Pre-test versus Retention were made using two separate, repeated measures ANOVAs for each of the three tests. For the clinical measures, the percent change was calculated as 100 multiplied by the difference between pre and post test scores, divided by pretest scores. For kinematic measures, the percent changes were calculated in similar fashion using start and end measures.

3. RESULTS

Kinematic analyses showed that, as a group, the subjects were able to more effectively control the limb during hand interaction with the target as demonstrated by improved proximal stability, smoothness and efficiency of the movement path. This was in concert with improvement in the distal kinematic measures of fractionation and improved timing.

There was a significant decrease in the time required to hammer each peg, ($F_{1,10}$ =11.9; p=.006), showing a 65% change. The hand path length improved significantly ($F_{1,10}$ =14.6; p=.003) , showing a 64% change, and there was an 81% improvement in smoothness of the trajectory ($F_{1,10}$ =5.2; p=.05). The improvement in movement time and path length appears to be related to changes in proximal segment function as finger extension did not change significantly. The improvements in smoothness are indicative of a decrease in the number of sub-movements required to complete the transport phase of the motion. Several authors cite this pattern of change as consistent with improvements in neuromotor control (Ferraro, et al., 2002; Rohrer, et al., 2004). A decrease in end-point deviation is an indicator of proximal stability. As a group, the subjects improved the proximal stability of the arm ($F_{1,10}$ =19.2; p=.001) while the fingers were repeatedly extending during the hammering task showing a 67% change in stability. Lang cites the ability to maintain proximal segments stationary during distal task performance as an important construct in overall upper extremity functional ability. Figure 4 displays the group average daily change in the piano task for accuracy of key presses (4a), average movement duration for each note in a song (4b), and finger fractionation (4c). Two subjects needed to use haptic assistance from the CyberGrasp for this activity and were therefore eliminated from the group calculations for fractionation (ability to isolate their finger movement). As a group the other nine subjects significantly improved in fractionation ($F_{1,8}$=5.2, p=.05) showing a 38% change. There was a significant improvement in the time to complete the task ($F_{1,10}$ =5.4, p=.04) showing a 13% change without a

©2010 ICDVRAT; ISBN 978 07049 15022

subsequent change in accuracy ($F_{1,10}$ =54, p=.48), indicating that the subjects were able to do the task faster while maintaining their accuracy. This pattern of improvement is thought to be consistent with motor learning (Krakauer, 2006).

These changes in kinematic measures were accompanied by robust changes in the clinical tests. There were statistically significant effects for each clinical test. Both pre-planned post hoc comparisons (Pre-test versus Post-test and Pre-test versus Retention) for each of the three clinical tests were also significant (Table 1). As a group, the 11 subjects showed a significant improvement in the WMFT ($F_{1,10}$ =12.5, p=.0003) showing a 25% (SD=11) improvement from Pre-test to Post-test. There also were significant improvements in JTHF ($F_{1,10}$ =10.07, p=.0009) with a 28% (15) change, and a 26% (30) change in the NHPT ($F_{1,10}$ =5.14, p=.0158).

As a way of interpreting the robust changes in the clinical tests, it is interesting to note that the mean (SD) decrease of 17 (7) sec. in the WMFT time (Table 1) substantially exceeds the reported group change of 2 seconds needed to be regarded as a clinically important difference on the WMFT. To indicate a true change for an individual subject in the time to complete the WMFT, that is a change beyond possible measurement error, the difference in score of an individual subject has to reach 4.36 sec (Lin, et al., 2009). In this study each subject exceeded the minimum detectable change of 4.36 seconds (range 5.7 to 33.2 sec). Additionally, Wolf et al. (2006) cite the completion of an item on a clinical test of upper extremity function at post-test, which a subject was unable to complete at pre-test, as a clinically significant change. One subject was unable to complete the checker task at pre-test but was able to do it at the retention test. This same subject was also unable to complete the picking up small objects and self feeding tasks of the JTHF at pre-test but did complete them at post-test and retention. Finally, two subjects were unable to complete the NHPT at pre-testing but were able complete it at post-testing and retention.

To evaluate the functional relevance of the observed improvement in the JTHF scores, we compared the performance of the hemiparetic arm with that of the arm ipsilateral to the lesion, as well as with the scores of nine age-matched, neurologically healthy controls. The control subjects were able to complete the six activities of the JTHF in 33 (7) sec using their dominant hand and in 36 (7) sec using their non-dominant hand. The subjects with stroke required 49 (12) sec to complete the six activities using their uninvolved hand and when using their impaired hand, improved from 161 (118) sec to 116 (78) sec with training (Fig. 5). Measures for the uninvolved hand and the controls were stable across the three time frames with only the hemiparetic hand showing improved scores.

Table 1. *Clinical Measurememnts.*

Test	Pre-Test (1) (sec)	Post-Test (2) (sec)	Retention (3) (sec)	F	P	Post Hoc (1-2) F	Post Hoc (1-2) P	Post Hoc (1-3) F	Post Hoc (1-3) P
WMFT	78 (57)	61 (54)	57(42)	7.86	.003	53.6	.0001	9.89	.01
JTHF	161 (118)	116 (78)	119(61)	5.04	.017	8.94	.014	5.19	.05
NHPT	189(174)	105(94)	100(64)	5.91	.0096	6.83	.03	6.89	.03

WMFT = Wolf Motor Function Test; JTHF = Jebsen Test of Hand Function; 9HPT=Nine Hole Peg Test.

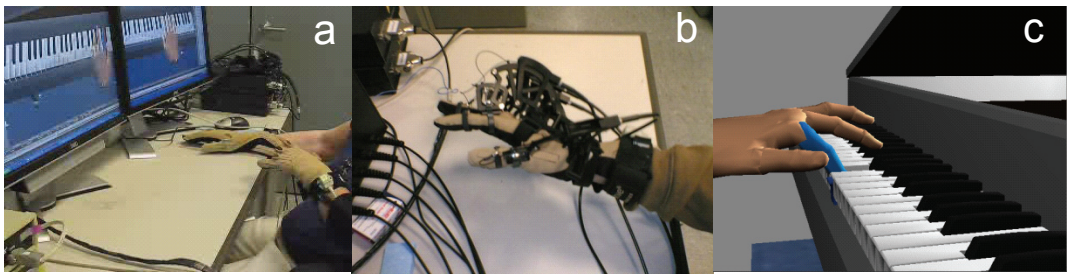


Figure 1. *Virtual Piano Trainer. (a) Picture of subject wearing a CyberGlove instrumented glove using the Piano Trainer Simulation; hands shown in a first person perspective. (b) CyberGrasp haptic device worn over a CyberGlove. (c) Picture of independent finger flexion as subject moves his hand to the cued key.*

©2010 ICDVRAT; ISBN 978 07049 15022

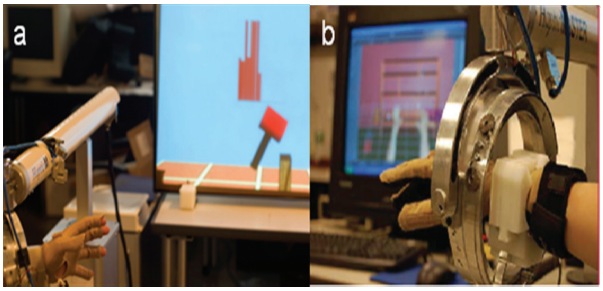


Figure 2. *NJIT-RAVR System. (a) Haptic Master, a 3 degrees of freedom, admittance controlled (force controlled) robot. (b) Three more degrees of freedom (yaw, pitch and roll) can be added to the arm by using a gimbal, with force feedback available only for (roll) pronation/supination.*

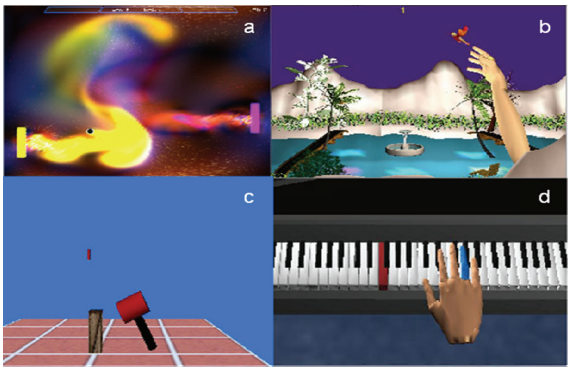


Figure 3. *HAT Training Simulations. (a) Pong paddle integrates shoulder flexion/extension and finger extension. (b) Hummingbird Hunt requires composite movement of arm transport, hand-shaping and grasp. (c) Hammer Task trains reaching and repetitive finger flexion/extension. (d) The Virtual Piano simulation consists of a complete virtual piano that plays the appropriate notes as they are pressed by the virtual fingers.*

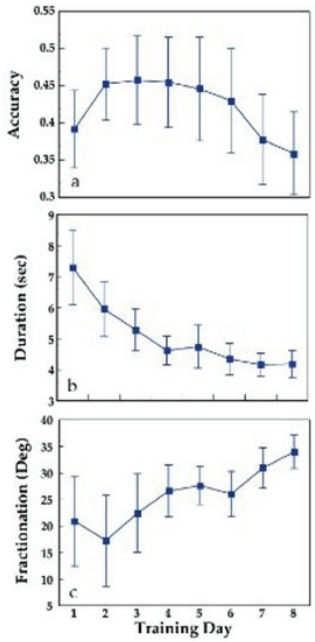


Figure 4. *Virtual Piano Trainer Kinematics. (a) Describes the daily changes in the subjects as a result of practice with the Virtual Piano. (b) While maintaining the accuracy of the key presses, the subjects were able to improve the timing of the songs and (c) increase their ability to isolate individual fingers.*

©2010 ICDVRAT; ISBN 978 07049 15022

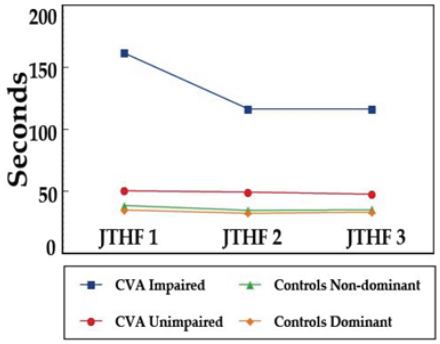


Figure 5. *Changes in Jebsen Test of Hand Function Score. Describes the changes in the JTHF in the hemiparetic hand as a result of training. This is compared to the stability of the measure in the uninvolved hand and in the control subjects.*

4. CONCLUSIONS

Our goal was to optimize training paradigms and enhance neuro-rehabilitation interventions. Specifically, to improve hemiparetic hand function by testing a rehabilitation paradigm that simultaneously exercised the proximal and distal components of the upper extremity using virtual reality task-based simulations interfaced with adaptive robots. Upper extremity and hand rehabilitation in particular, is a challenge in stroke rehabilitation. It remains controversial as to the most advantageous method of hand rehabilitation. It is therefore important to compare the clinical changes achieved in this study to results from other studies performed in both our lab and others. Krebs et al (2008) compared a robotically facilitated program of planar reaching tasks emphasizing proximal function to two different approaches combining robotically facilitated proximal movement integrated with manual interaction with real or simulated objects (Krebs, et al., 2008). The group training isolated proximal function made larger improvements in shoulder and elbow upper extremity Fugl -Meyer Assessment score when compared to each of the two hand and arm training groups. But those that trained the whole arm showed greater changes in the wrist/hand portion of the Fugl-Meyer. In our lab, in a former study of comparable duration, that trained the hand only, the subjects showed a 10% improvement in the time of the JTHF (Merians, et al., 2006), while in this current study that trained the arm and hand simultaneously, subjects showed a 28% change in the time needed to complete all the items on the JTHF. When we trained the hand alone, the gaming simulations were very simple activities, requiring only control of wrist and finger movement. Whereas in this study the activities required by the gaming simulations were more complex and required simultaneous control of integrated shoulder, elbow, forearm, wrist and finger movements.

Congruent with the motor learning and neuroplasticity literature, it is believed that the acquisition of a skill follows a dose–response relationship (Kwakkel, 2006). Subjects average over 500 repetitions/day in studies in the robotic rehabilitation literature (Aisen, et al., 1997; Aubert, et al., 2005; Dipietro, et al., 2008) while an observational study of the repetitions performed in a traditional outpatient setting averaged 85 (Lang, et al., 2007). The average number of repetitions during the two to three hour training sessions used in this study exceeded 2200. Each training session in this study was considerably longer than the twenty to ninety minute sessions described in the current robotic literature (Kwakkel, et al., 2008; Mehrholz, et al., 2009) and was delivered within a more concentrated time period (Daly, et al., 2005; Dipietro, et al., 2008; Fasoli, Krebs, Stein, Frontera, & Hogan, 2003; Kahn, Lum, Rymer, & Reinkensmeyer, 2006; Lum, Burgar, & Shor, 2004).

Our hypothesis for the use of a virtual reality/robotic system for rehabilitation are that in addition to providing a motivating environment for repetitive task practice, this medium can provide adaptive learning algorithms to create individualized motor learning paradigms. In this study the largest improvements demonstrated with the Virtual Piano Trainer were for finger fractionation, which is the ability to flex one finger independently of the other fingers. Fractionation is specifically reinforced with an adaptive algorithm which increases and decreases the fractionation target, based on the subjects' performance. This algorithm is described in detail elsewhere (S. Adamovich, et al., 2009). Subjects made larger improvements in fractionation than in speed or accuracy, which were not shaped with an algorithm or reinforced with feedback. These results are congruent with those of Lum et al, (Lum, et al., 2004) who found that subjects with strokes, training using the MIME system, reduced force direction errors when this construct was shaped with an algorithm.

©2010 ICDVRAT; ISBN 978 07049 15022

Essential factors such as the dosage and intensity of the practice, the drive provided by specific algorithms as well as the complexity of the gaming simulations appear to have had a substantial, positive effect on our goal of improving hemiparetic hand function. In conclusion, we have designed a library of complex gaming simulations that are interfaced with robotic devices that can train the entire upper extremity of patients post-stroke. In preliminary studies, using this technology, patients with a range of sensorimotor upper extremity impairments have made robust changes in functional tests of upper extremity motor control.

Acknowledgements: This work was supported in part by NIH grant HD 42161 and by the National Institute on Disability and Rehabilitation Research RERC (Grant # H133E050011).

5. REFERENCES

S V Adamovich, G G Fluet, A Mathai, , Q Qiu, J Lewis, & A S Merians (2009) Design of a complex virtual reality simulation to train finger motion for persons with hemiparesis: a proof of concept study. *J Neuroeng Rehabil,* **6**, *28*.

S V Adamovich, G G Fluet, A S Merians, A Mathai & Q Qiu (2009) Incorporating haptic effects into three-dimensional virtual environments to train the hemiparetic upper extremity. *IEEE Trans Neural Syst Rehabil Eng,* **17,** *5*, 512-520.

M L Aisen, H I Krebs, N Hogan, F McDowell & B T Volpe (1997). The effect of robot-assisted therapy and rehabilitative training on motor recovery following stroke. *Arch Neurol,* **54**,*4*, 443-446.

C Ansuini, M Santello, F Tubaldi, S Massaccesi & U Castiello. (2007) Control of hand shaping in response to object shape perturbation. *Exp Brain Res,* **180,** *1*, 85-96.

J R Charles, S LWolf, J A Schneider & A M Gordon. (2006) Efficacy of a child-friendly form of constraint-induced movement therapy in hemiplegic cerebral palsy: a randomized control trial. *Dev Med Child Neurol,* **48**, *8*, 635-642.

A B Conforto, L G Cohen, R L dos Santos, M Scaff & S K Marie (2007) Effects of somatosensory stimulation on motor function in chronic cortico-subcortical strokes. *J Neurol,* 254, *3*, 333-339.

L H Daltroy, C B Phillips, H M Eaton, M G Larson, A J Partridge, M Logigian, et al. (1995) Objectively measuring physical ability in elderly persons: the Physical Capacity Evaluation. *Am J Public Health, **85,** 4*, 558-560.

J J Daly, N Hogan, E M Perepezko, H I Krebs, J M Rogers, K S Goyal, et al. (2005) Response to upper-limb robotics and functional neuromuscular stimulation following stroke. *J Rehabil Res Dev,* **42**, *6*, 723-736.

L Dipietro, H I Krebs, S E Fasoli, B T Volpe, & N Hogan. (2008) Submovement changes characterize generalization of motor recovery after stroke. *Cortex*.

S E Fasoli, H I Krebs, J Stein , W R Frontera, & N Hogan (2003) Effects of robotic therapy on motor impairment and recovery in chronic stroke. *Arch Phys Med Rehabil,* **84**,4, 477-482.

M Ferraro, J H Demaio, J Krol, C Trudell, K Rannekleiv, L Edelstein, et al. (2002) Assessing the motor status score: a scale for the evaluation of upper limb motor outcomes in patients after stroke. *Neurorehabil Neural Repair, **16**,3*, 283-289.

R H Jebsen, N Taylor, R B Trieschmann, M J Trotter, & L A Howard (1969) An objective and standardized test of hand function. *Arch Phys Med Rehabil, **50**,6*, 311-319.

L E Kahn, P S Lum, W Z Rymer & D J Reinkensmeyer (2006) Robot-assisted movement training for the stroke-impaired arm: Does it matter what the robot does? *J Rehabil Res Dev,* **43**,*5*, 619-630.

J W Krakauer (2006) Motor learning: its relevance to stroke recovery and neurorehabilitation. *Curr Opin Neurol, 19*(1), 84-90.

H I Krebs, S Mernoff, S E Fasoli, R Hughes, J Stein, & N Hogan. (2008) A comparison of functional and impairment-based robotic training in severe to moderate chronic stroke: a pilot study. *NeuroRehabilitation, **23**,1*, 81-87.

G Kwakkel (2006) Impact of intensity of practice after stroke: issues for consideration. *Disabil Rehabil,* **28**,*13-14,* 823-830.

G Kwakkel, B J Kollen, & H I Krebs (2008) Effects of robot-assisted therapy on upper limb recovery after stroke: a systematic review. *Neurorehabil Neural Repair,* **22**,*2*, 111-121.

C E Lang, J R MacDonald, & C Gnip (2007) Counting repetitions: an observational study of outpatient therapy for people with hemiparesis post-stroke. *J Neurol Phys Ther,* **31**,1, 3-10.

S Lennon, A Ashburn & D Baxter (2006). Gait outcome following outpatient physiotherapy based on the Bobath concept in people post stroke. *Disabil Rehabil,* **28,** *13-14*, 873-881.

M F Levin, S M Michaelsen, C M Cirstea, & A Roby-Brami (2002) Use of the trunk for reaching targets placed within and beyond the reach in adult hemiparesis. *Exp Brain Res,* **143**, *2*, 171-180.

K C Lin, Y W Hsieh, C Y Wu, C L Chen, Y Jang, & J S Liu (2009) Minimal detectable change and clinically important difference of the Wolf Motor Function Test in stroke patients. *Neurorehabil Neural Repair, **23**,5*, 429-434.

P S Lum, C G Burgar, & P C Shor (2004). Evidence for improved muscle activation patterns after retraining of reaching movements with the MIME robotic system in subjects with post-stroke hemiparesis. *IEEE Trans Neural Syst Rehabil Eng,* **12**,2, 186-194.

V Mathiowetz, G Volland, N Kashman, & K Weber (1985) Adult norms for the Box and Block Test of manual dexterity. *Am J Occup Ther,* **39**,6, 386-391.

J Mehrholz, T Platz, J Kugler, & M Pohl (2009) Electromechanical and Robot-Assisted Arm Training for Improving Arm Function and Activities of Daily Living After Stroke. *Stroke*.

A S Merians, H Poizner, R Boian, G Burdea, & S Adamovich (2006). Sensorimotor training in a virtual reality environment: does it improve functional recovery poststroke? *Neurorehabil Neural Repair,* **20**, *2*, 252-267.

A S Merians, E Tunik & S V Adamovich (2009) Virtual reality to maximize function for hand and arm rehabilitation: exploration of neural mechanisms. *Stud Health Technol Inform, 145*, 109-125.

M Merzenich, B Wright, W Jenkins, C Xerri, N Byl, S Miller et al. (1996) Cortical plasticity underlying perceptual, motor, and cognitive skill development: implications for neurorehabilitation. *Cold Spring Harb Symp Quant Biol,* **61** 1-8.

S M Michaelsen, S Jacobs, A R oby-Brami, & M F Levin (2004) Compensation for distal impairments of grasping in adults with hemiparesis. *Exp Brain Res,* **157**,*2*, 162-173.

SM Michaelsen, A Luta, A Roby-Brami & M F Levin (2001) Effect of trunk restraint on the recovery of reaching movements in hemiparetic patients. *Stroke,* **32**,8, 1875-1883.

R J Nudo, G W Milliken, W M Jenkins & M M Merzenich (1996) Use-dependent alterations of movement representations in primary motor cortex of adult squirrel monkeys. *J Neurosci,* **16**,*2*, 785-807.

E J Plautz, G W Milliken & R J Nudo (2000) Effects of repetitive motor training on movement representations in adult squirrel monkeys: role of use versus learning. *Neurobiol Learn Mem,* **74**,*1*, 27-55.

Q Qiu, GG Fluet, I Lafond, A S Merians & SVAdamovich (2009) Coordination changes demonstrated by subjects with hemiparesis performing hand-arm training using the NJIT-RAVR robotically assisted virtual rehabilitation system. *Conf Proc IEEE Eng Med Biol Soc,* 1143-1146.

B Rohrer, S Fasoli, H I Krebs, B Volpe, W R Frontera, J Stein, et al. (2004) Submovements grow larger, fewer, and more blended during stroke recovery. *Motor Control,* **8**,4, 472-483.

S L Wolf, P A Thompson, D M Morris, D K Rose, C J Winstein, E Taub, et al. (2005). The EXCITE trial: attributes of the Wolf Motor Function Test in patients with subacute stroke. *Neurorehabil Neural Repair,* **19**,*3*, 194-205.

S L Wolf, C J,Winstein J P Miller, Taub, E., Uswatte, G., Morris, D., et al. (2006). Effect of constraint-induced movement therapy on upper extremity function 3 to 9 months after stroke: the EXCITE randomized clinical trial. *Jama,* **296**, 17, 2095-2104.

©2010 ICDVRAT; ISBN 978 07049 15022

A study to evaluate a low cost virtual reality system for home based rehabilitation of the upper limb following stroke

PJ Standen[1], D J. Brown[2], S Battersby[2], M Walker[1], L Connell[1], A Richardson[3], F Platts[4], K Threapleton[1], A Burton[2]

[1]Division of Rehabilitation and Ageing, University of Nottingham, Nottingham, UK

[2]Computing and Technology Team, School of Science and Technology, Nottingham Trent University, UK

[3]Erewash Community Occupational Therapy Service, Derbyshire, UK

[4]Nottinghamshire Community Health NHS Trust, Nottinghamshire, UK,

p.standen@nottingham.ac.uk, david.brown@ntu.ac.uk, steven.battersby@ntu.ac.uk, marion.walker@nottingham.ac.uk, louise.connell@nottingham.ac.uk, andy.richardson@derbyshirecountypct.nhs.uk, fran.platts@nottscommunityhealth.nhs.uk, kate.threapleton@nottingham.ac.uk, andy.burton@ntu.ac.uk

[1]*www.nottingham.ac.uk.*, [2]*www.ntu.ac.uk*, [4] *www.nottscommunityhealth.nhs.uk.*

ABSTRACT

Stroke survivors with continuing impairment in their upper limb find it difficult to access the early intensive, task specific practice that research has shown is necessary for motor recovery. A systematic review of studies that investigate the effects of robot-assisted therapy on motor and functional recovery in patients with stroke found significant improvement in upper limb motor function but the systems reviewed are expensive, require technical support and are hospital or laboratory based. This paper describes the development of a low cost home based system together with a suite of games which would allow patients to practice the movements required for activities of daily living at the frequency required. The ongoing feasibility study is described.

1. INTRODUCTION

Between 55 and 75% of stroke survivors fail to regain functional use of their impaired upper limb (Feys et al., 1998). Upper limb motor impairment limits the individual's functional autonomy and activities of daily living, impacting negatively on participation and quality of life (Nichols-Larsen, 2005).

The evidence for stroke rehabilitation suggests that early intensive (Kwakkel et al., 2004), task specific (van Peppen et al., 2004) practice for a prolonged period of time (van der Lee et al., 2001) facilitates motor recovery. A meta-analysis by Kwakkel et al (2004) concluded that "augmented exercise therapy has a small but favorable effect on ADL, particularly if therapy input is augmented at least 16 hours within the first 6 months after stroke". Reviewing studies where constraints were applied to the less affected arm and thus forcing patients to use the affected arm for "6 hours per day during 2 weeks" (ie, augmentation of 60 hours) led them to conclude that "a high dose of task-specific exercise training should be applied over a shorter period of time. Therefore, research on subjects likely to benefit from higher intensities of stroke rehabilitation should be part of the future research agenda."

In view of the evidence, in the UK the National Clinical Guidelines for Stroke recommend that patients should undergo as much therapy appropriate to their needs as they are willing and able to tolerate (3.13.1). However in practice the intensity and duration of therapy is limited by resources. According to Kwakkel et al (2004) in stroke units the usual direct contact time may be as little as 4% of the total waking time. Patients on the stroke unit in Nottingham were found to spend on average only one hour per day in any type of therapy (Putman et al, 2006) and the median length of stay is now as short as 28 days. In order to prepare the patient for discharge, the focus of rehabilitation while on the unit is on mobility rather than upper limb function (Putman et al, 2006). Following discharge therapy is commonly delivered in patients' homes either by the community stroke teams or under an early supported discharge scheme. However, this support provides on average only six weeks of treatment. A Cochrane review has demonstrated that therapy-based services for stroke patients at home after stroke are effective, however it is not clear what the exact nature and content of

©2010 ICDVRAT; ISBN 978 07049 15022

the rehabilitation should be (Outpatient ServiceTrialists, 2003). Patients with stroke living at home have identified upper limb therapy as an unmet need (Vincent et al, 2007), but the optimal intensity and dose of therapy is unclear.

As yet the definitive number of repetitions of a task required to drive the neural changes for optimal recovery post stroke is not known. A study by Lang et al (2009) found patients carried out an average of 32 functional upper limb movement repetitions during therapy sessions. This falls short of the large doses of practice (in the order of hundreds) that has been found to be effective in animal models. Therefore access to therapy is limited compared to the amount needed to drive neural change and what therapy there is, is not focussed on treatment of the upper limb.

There has been a paradigm shift in rehabilitation with the focus on empowering the patient, self-management and provision of therapy outside of the acute setting. This, combined with the evidence for the intensity of practice required and the limited resources available, has led to interest in the efficacy and efficiency of delivering therapy in novel ways. It has been recognised that face to face contact with a therapist is not the only way to deliver therapy, and may not be the most efficient way. The growing interest in the application of emerging technologies to augment rehabilitation has been endorsed by both the UK national stroke research network and the priority research areas set in the UK National Stroke Strategy. Of these technologies, Virtual Reality (VR) rehabilitation has been heralded as one of the most promising methods for maximizing the intensity and convenience of task specific rehabilitation training (Dobkin, 2004). Long-term participation of stroke survivors in exercise programmes is poor and a further benefit to application of novel technologies to deliver task-specific practice may be improved adherence. The aesthetics and affective properties of rehabilitation are often not considered but are important for sustainability (Rhodes & Fiala, 2009). Thus the use of VR rehabilitation and social interaction may be effective in maintaining motivation and alleviating boredom (Bonk et al, 2001, Sander et al, 2002, Yamashita et al, 2006).

Preliminary research in the area of VR stroke rehabilitation focused primarily on examining the feasibility of complex VR systems that provide the participants with different types of augmented feedback (eg van Dijk et al, 2005) and different VR rehabilitation protocols for acute, sub-acute and chronic stroke patients (eg Merians et al., 2002). Although this work mainly involved small sample sizes it suggested promising trends, triggered the active exploration of telerehabilitation applications (eg Broeren et al., 2004) and finally led to further studies involving bigger sample sizes (Holden et al., 2007) and small controlled clinical trials (eg Piron et al., 2006; Crosbie et al, 2008). This later work established the feasibility, health and safety of VR stroke rehabilitation systems and indicated that previously obtained positive outcomes were not attributed to spontaneous recovery (Holden et al., 2007). Neuroimaging studies also demonstrated that VR training can induce cortical reorganization following stroke (Takahashi et al., 2008). In a systematic review of studies that investigate the effects of robot-assisted therapy on motor and functional recovery in patients with stroke Kwakkel, Kollen & Krebs (2008) found significant improvement in upper limb motor function but not ADL after stroke for upper arm robotics.

Given the fact that most of the above systems employ relatively sophisticated or expensive hardware and software, one question of paramount clinical importance is whether the benefits obtained from these systems can outweigh their cost or if similar results can be obtained with less sophisticated affordable systems. What now needs to be explored is the rehabilitation potential of commonly available VR platforms and games. Although commercially available platforms lack specificity in terms of software, hardware and performance metrics they often provide other equally important advantages such as mass acceptability, easily perceived feedback and most importantly affordability for unrestricted home use. In an earlier study (Chortis et al, 2008) we investigated the use of a commercially available game controller the Novint Falcon *http://home.novint.com/products/novint_falcon.php* that came with a variety of VR minigames that should motivate users to perform sufficient repetition of tasks. The controller has the advantage of including force feedback which should increase the effectiveness of the participants' actions. Saposnick et al (2010) carried out a feasibility study using Nintendo's Wii together with two of the games suites available with the system. Both of these studies produced promising results however, the interventions employed suffer from two notable drawbacks. First, both controllers require the player to have the ability to grip them for prolonged periods of time. While they allow practice of arm movements, they exclude the practice of grasp and release: a particular challenge to many stroke patients but necessary for many activities of daily living. Second, the games made available with the controllers were not specifically designed with these users in mind and may not actually practice the movements which therapists recommend for recovery of independent functioning.

To overcome these drawbacks, our team have been developing a system that tracks infra-red light emitting diodes (LEDs) positioned on the fingers: a virtual glove (Battersby, 2008; Barker, 2009). This translates the actions of reach, grasp and release into game play but would still be low cost, lightweight, easy to set up in users' homes but would lack the force feedback of the Novint Falcon. This might reduce the

©2010 ICDVRAT; ISBN 978 07049 15022

effectiveness of the participants' actions but this would be more than compensated for by the inclusion of grasp and release tasks. In collaboration with user representatives, a suite of three games have been developed that encourages the participant to practice the movements required for activities of daily living. However, unlike commercially available games, this software allows calibration to each user so that even those with limited ability can perform a movement sufficient to achieve a score. For example, initially quite a large gap between thumb and fingers would qualify as a "grasp" but as the user improves, the distance between thumb and fingers necessary to gain a score can be reduced. In order to maintain motivation, the level of challenge can be varied to suit the user in other ways such as increasing the number of tasks that need to be completed or increasing the speed at which stimuli/targets appear on the screen. In addition to calculating and displaying a score so that the user can track their progress, the software collects data on the number of movements made by the user whether they are successful in achieving a score or not.

New gaming devices are frequently appearing so it may soon be possible to identify a low cost commercially available system that overcomes any physical shortcomings in those devices currently available. Given the systems currently available, it is important to investigate whether the hardware and software are practical to use and sufficiently motivating that individuals perform the required number of repetitions of upper limb movements for an improvement in arm function. Nonadherence is common when treatment regimes require prolonged and unsupervised self management (Carter, Taylor, & Levenson, 2003) and between 60% and 80% of people receiving treatment admit to partial or complete nonadherence to home-based exercises (Engström & Öberg, 2005; Sluijs, Kerssens, van der Zee, & Myers, 1998).

It is the future intention of the team to carry out a definitive study to determine the effectiveness of home use of the virtual glove to improve upper limb function in patients recovering from a stroke. Before this can be done, certain crucial information needs to be collected in order to reach the correct design for the main study. The current study is therefore to determine the feasibility of the main study and to pilot whether the components of the main study can all work together. The study will follow the MRC guidelines for feasibility and pilot testing from the framework for evaluating complex interventions (*http://www.hta.ac.uk/funding/troubleshooting/standardcalls.html*).

2. METHODS

2.1 Development methodology

In order to develop the prototype glove and games a user sensitive design methodology was employed that we have previously reported (Brown et al, 2005). This combines established guidelines on User Centred Design, for example USERfit (Poulson et al, 1996) with contemporary HCI and product design research. It is a six stage, iterative, design process in which users are involved at all stages. User input is managed in two ways. First a multidisciplinary Usability Team guide the application of the user sensitive design methodology. This group included occupational and physiotherapists with expertise in stroke rehabilitation as well as researchers with expertise in ergonomics, HCI, manufacturing, experimental design, and product design. Second, a user team contributed to the design process by proposing design requirements and how these could be met in potential design solutions and giving feedback on the prototypes developed. Users were recruited from the Nottingham Stroke Research Consumer Group, Nottingham City Stroke Club and patients and therapists from two local specialist rehabilitation centres.

2.2 Development of the virtual glove

2.2.1 Version 1. The first version of the glove consisted of four light emitting diodes sown into the fingertips of a normal glove (see Figure 1) whose position was tracked with the aid of 2 Nintendo Wiimotes attached to the top of a 24" flat screen monitor. This allows the triangulation of the position of the infrared source and produces a set of 3D coordinates. The decision to use 4 diodes per glove was based on the capacity of the infrared receiver used to pick up the signal from the diodes. As the position of the ring finger is predictable from the position of the fingers either side in most movements, the four diodes were placed on the remaining fingers and the thumb. Testing was carried out with multiple voltages to determine the minimum rating that could be used to run a single diode. A single 1.5V battery (AA) was enough to power the glove of 4 diodes. However, each glove had a battery pack attached that produces 3 volts from 2 AA batteries. This gave the glove a longer life span and a strong signal which improved the responsiveness and accuracy of the system. Including more batteries than this, for example 6V would mean that 4 batteries were required per glove, and this would have seriously impacted on the usability of this device for users recovering from stroke. This version of the glove also included an accelerometer and two linear potentiometers similar to those found inside a Wii Nunchuck controller. The idea behind these additions was that they might be useful to free up analogue inputs to measure strain or hand closure and potentially implement either a fifth finger or more robust information on thumb position. This could also have removed the need for 2 Wiimotes for

©2010 ICDVRAT; ISBN 978 07049 15022

triangulating position. Unfortunately, including all these components in the pack on the back of the hand produced too much bulk and weight especially for the target user group.

2.2.2 Version 2. Feedback from therapists indicated that a real glove would not be acceptable to users due to comfort and hygiene issues. This version therefore used hook and loop tape to affix the power pack to the back of the hand and plastic "thimbles" to hold the LEDs (see Figure 2). Users preferred a glove where these thimbles were attached to the power pack with cables to avoid dropping or losing them. This choice led us to reject the proposal to include a wireless transmitter in the power pack. To reduce bulk and weight, the potentiometers were omitted from this version.

2.2.3 Version 3. At this point it was decided to further reduce the bulk and weight of the power pack by omitting the accelerometers and providing the power through two CR2032 batteries. Removal of the accelerometers creates a need to track the horizontal angle of the hand using the diodes alone. This can be achieved by a 'line-of-best-fit' regression calculation treating the diode x and y positions as though they were points on a graph. Removing the accelerometers does however increase the difficulty of deciphering which diode is which or 'point filtering' and for more complex 3D game interaction, a rugged algorithm and calibration method may need to be developed to achieve this with diodes alone. To cope with varying sizes of finger, LEDs were attached using double sided hook and loop cable ties (see Figure 3). Reducing the weight and bulk of the pack attached to the back of the hand gives the potential to include a usb charging circuit for a 5V rechargeable battery if users prefer this to changing the CR2032 batteries when they are depleted.

Figure 1. *Version 1 of the virtual glove*

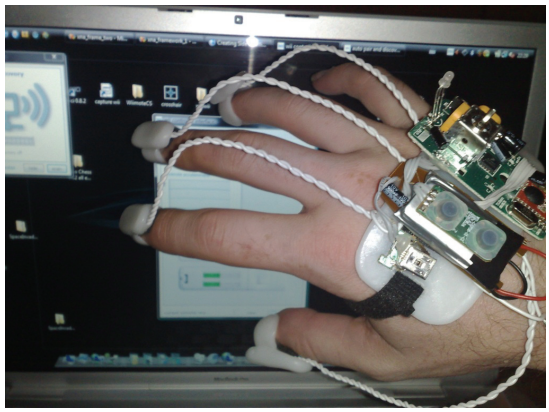


Figure 2. *Version 2 of the virtual glove*

2.3 Development of the games

A suite of 3 games was developed based on suggestions received from the Nottingham Stroke Research Consumer group and participants in the pilot study that would involve frequent repetitions of upper limb movements (i.e. pull, push, reach, grasp) that are necessary to effect many activities of daily living. Figures 4 and 5 show a screenshot from one of the games and illustrate how the player has to rotate the wrist to navigate the spaceship through the slot in the approaching wall. Each game has different levels varying in the standard of the movement required to achieve a score, the speed at which events occur and with which responses are required as well as in complexity of challenge in order to keep the participants motivated to continue to use the system but to ensure that they can achieve some success. Participants' scores are displayed on the screen at the end of a game and there is a permanent visual display of their progress in terms of scores and levels played. Once they have achieved a critical score at one level they are offered the option of progressing to the next level. When a participant returns to a game either at the beginning of a session or after playing another game, they have the opportunity to continue at the level they were at previously or, if the critical performance has been achieved, of moving on to the next level. Offering the participant the option to remain at the lower level ensures they are not presented with too much of a challenge before they refamiliarise themselves with the game's requirements. A log of when the system is in use is collected by the computer as well as what games are being played and what scores the user obtains. In order to distinguish between use by the participant and use by any other friends or relatives, a user has to enter a code number

©2010 ICDVRAT; ISBN 978 07049 15022

before they can play so that only the performance metrics of the participant are logged in the database. The Games were written with Microsoft's XNA Game Development Framework and utilise Brian Peek's WiimoteLib (a .NET managed library for using a Nintendo Wii Remote and extension controllers from a .NET application *http://www.brianpeek.com*) and several accompanying Wiici (Wii Controller Interface) Libraries developed by the third author to enable the device to communicate with the games.

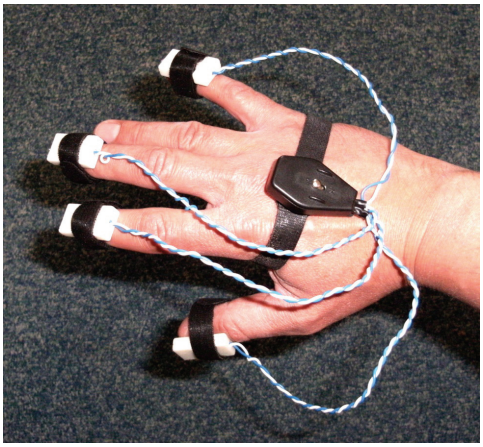


Figure 3. *Version 3 of the virtual glove*

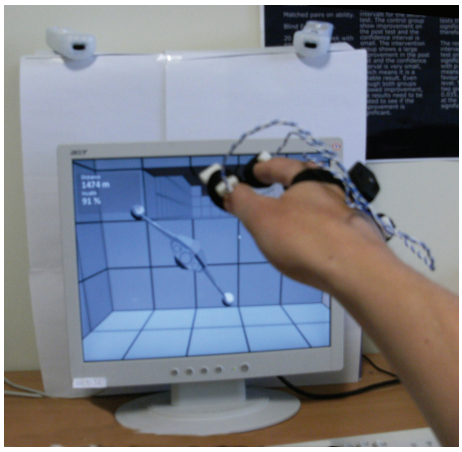


Figure 4. *Space race game showing player's hand position*

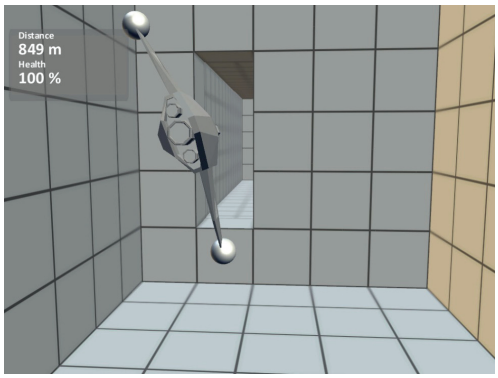


Figure 5. *Screenshot of the space racegame*

2.4 The study

2.4.1 Design. The glove is being evaluated using a two group randomised control trial to compare the glove with usual care.

2.4.2 Participants. 60 patients aged 18 or over are being recruited, who have a confirmed diagnosis of their first stroke, who are no longer receiving any other rehabilitation therapy and who still have residual upper limb dysfunction.

2.4.3 Intervention. Patients will be randomly allocated to either the intervention group or the control group. Those patients in the intervention groups would have the virtual glove in their homes (see Figure 6) for a period of 10 weeks. In order to achieve the recommended exposure time of 60 hours (Kwakkel et al, 2004) they will be advised to use the system for 20 minutes 3 times a day for 10 weeks to make allowance for missed days or missed sessions.

©2010 ICDVRAT; ISBN 978 07049 15022

Figure 6. *How the equipment might look set up in a participant's home.*

2.4.4 Outcome measures. Wolf motor functions test (Wolf et al, 1989): a measure of upper limb functioning; Nine-Hole Peg Test (Kellor et al, 1971) a test of fine motor co-ordination and the Nottingham Extended Activities of Daily Living (Nouri & Lincoln, 1987) a measure of functional ability that is commonly used in studies of stroke rehabilitation. It has four subscales: mobility, kitchen tasks, domestic tasks, leisure activities. For the intervention group the frequency of use of the equipment will be collected by the software and the frequency of requests for help and type of queries when using the equipment will be logged by the research team to provide information on feasibility of using the equipment and aspects of the intervention that may influence its adoption.

2.4.5 Provision of support for participants during the trial. One of the biggest challenges to the evaluation is participant failure to adhere to the proposed frequency of use of the system. Several procedures have therefore been planned to encourage participants to use the equipment at the recommended frequency. First, considerable face to face support will be provided. When the equipment is delivered and set up it will be demonstrated to the participant and their carer. A member of the research team will then use the equipment with the participant and observe them using it independently. The researcher will then arrange to return within the next two or three days to repeat this demonstration. If after this visit they feel that the participant has understood how to use the equipment or that there is a carer who understands how to use it, the intervention can commence and the researcher will phone the participant after two days to check that they have been able to use the equipment in its intended manner and offer to visit once more to clarify any outstanding matters. If they still seem unsure of how to use it by the end of the second visit the researcher will arrange to visit again in the next 48 hours. A member of the team will then visit fortnightly to retrieve data and check progress. Second, the participant will be given a phone number on which a member of the research team can be contacted during working hours if they need any advice or if the equipment fails. Third, they will also be provided with an instruction manual which will include Frequently Asked Questions and troubleshooting tips. This will also be available on the project web page for those who have internet access. A record of how many demonstration visits took place and the number and type of requests for help will be recorded as well as the number of extra visits and notes kept of any queries or problems that are raised in each visit or phone call.

3. CONCLUSIONS

A user sensitive design methodology has been successfully employed to develop a virtual glove and a suite of three games that encourage practice of the movements that are essential for activities of daily living for people experiencing problems with their upper limb following a stroke. A randomised control trial to determine the feasibility of a full definitive trial of its evaluation has just commenced.

Acknowledgements: This trial is funded by the NIHR through the Nottingham, Derby and Lincoln Collaboration for Leadership in Applied Health Research and Care.

4. REFERENCES

M Barker (2009), Wiimote Based Stroke Rehabilitation System. *Undergraduate thesis, Nottingham Trent University.*

©2010 ICDVRAT; ISBN 978 07049 15022

S J Battersby (2008), The Nintendo Wii controller as an adaptive assistive device – a technical report**,** *HEA ICS Supporting Disabled Students through Games Workshop*, Middlesborough, 4th February 2008.

D J Brown, S J Battersby, P J Standen and N Anderton N (2005), Inclusive design for disability. A prototype switch for use in virtual learning environments. *International Journal of Disability and Human Development* , **4**, *2*, pp. 103-119.

V A Bonk, C R France and B K Taylor (2001), Distraction reduces self-reported physiological reactions to blood donation in novice donors with a blunting coping style, *Psychosomatic Medicine*, **63**, pp. 447–452.

J Broeren, M Rydmark and K Sunnerhagen (2004), Virtual reality and haptics as a training device for movement rehabilitation after stroke: a single-case study, *Archives of Physical Medicine and Rehabilitation,* **85**, *8*, pp. 1247-50.

S Carter, D Taylor and R Levenson (2003), A *question of choice—Compliance in medicine taking.* Medicines Partnership. London.

Chortis A, Standen PJ, Walker M (2008) Virtual reality system for upper extremity rehabilitation of chronic stroke patients living in the community. *Proceedings of the Seventh International Conference on Disability, Virtual Reality and Associated Technologies* with *Artabilitaion, in* P. M. Sharkey, P. Lopes-dos-Santos, P.L. Weiss & A.L. Brooks (Eds.), 221-228, Maia, Portugal, 8-11 Sept. 2008.

J H Crosbie, S Lennon, M C McGoldrick, M D J McNeill, J W Burke and S M McDonough (2008), Virtual reality in the rehabilitation of the upper limb after hemiplegic stroke: a randomised pilot study, *Proceedings of the Seventh International Conference on Disability, Virtual Reality and Associated Technologies* with *Artabilitaion, in* P. M. Sharkey, P. Lopes-dos-Santos, P.L. Weiss & A.L. Brooks (Eds.), 229-235, Maia, Portugal, 8-11 Sept. 2008.

B H Dobkin (2004), Strategies for stroke rehabilitation, *Lancet Neurology,* **3**, *9*, pp. 528-36.

L O Engström, and B Öberg (2005), Patient adherence in an individualized rehabilitation programme: A clinical follow-up, *Scandinavian Journal of Public Health,* **33**, pp. 11–18.

H M Feys, W J De Weerdt, B E Selz, G A Cox Steck, R Spichiger, L E Vereeck, K D Putman and G A Van Hoydonck (1998), Effect of a therapeutic intervention for the hemiplegic upper limb in the acute phase after stroke, *Stroke,* **29**, pp.785-792.

M K Holden, T A Dyar and L Dayan-Cimadoro (2007), Telerehabilitation using a virtual environment improves upper extremity function in patients with stroke, *IEEE Transactions on Neural Systems and Rehabilitation Engineering,* **15**, *1*, pp. 36-42

M Kellor, J Frost, N Silberberg, I and R Cummings (1971), Hand strength and dexterity, *American Journal of Occupational Therapy*, **25**, pp. 77 – 83.

G Kwakkel, R van Peppen, R C Wagenaar, S Wood-Dauphinee, C Richards, A Ashburn, K Miller, N Lincoln, C Partridge, I Wellwood and P Langhorne (2004), Effects of augmented exercise therapy time after stroke: a meta-analysis, *Stroke*, **35**, *11*, pp. 2529-39.

G Kwakkel, B J Kollen and H I Krebs (2008), Effects of robot-assisted therapy on upper limb recovery after stroke: a systematic review, *Neurorehabilitation and Neural Repair,* **22**, *2*, pp. 111-121.

C E Lang, J R MacDonald, D S Reisman, L Boyd, T J Kimberley, S M Schindler-Ivens, T G Hornby, S A Ross and P L Scheets (2009), Observation of amounts of movement practice provided during stroke rehabilitation, *Archives of Physical Medicine and Rehabilitation*, **90**, 10*,* pp. 1692-1698.

A Merians, D Jack, R Boian, M Tremaine, G Burdea, S Adamovich, M Recce and H Poizner (2002), Virtual reality-augmented rehabilitation for patients following stroke, *Physical Therapy,* **82**, *9*, pp. 898-915.

D S Nichols-Larsen, P C Clark and A Zeringue (2005), Factors influencing stroke survivor's quality of life during subacute recovery, *Stroke,* **36**, pp. 1480-84.

F Nouri and N Lincoln (1987), An extended ADL scale for stroke patients, *Clinical Rehabilitation*, **1**, pp. 301-5.

Outpatient ServiceTrialists.Therapy-based rehabilitation services for stroke patients at home. *Cochrane Database of Systematic Reviews* 2003, Issue 1. Art. No.: CD002925. DOI: 10.1002/14651858.CD002925.

L Piron, P Tonin, F Cortese, M Zampolini, F Piccione, M Agostini, C Zucconi, A Turolla and M Dam (2006), Post-stroke arm motor telerehabilitation web-based, *Proceedings of IEEE 5th International Workshop Virtual Rehabilitation*, pp.145–148.

D Poulson, M Ashby, S Richardson (1996), *USERfit: A practical handbook on user centred design for assistive technology.* ECSC-EC-EAEC, Brussels-Luxembourg.

K Putman, L De Wit, L Connell et al (2006), Use of time by physiotherapists and occupational therapists in a stroke rehabilitation unit: A comparison between four European centres, *Disability and Rehabilitation*, **28**, 2*2*, pp. 1417-1424.

R E Rhodes and B Fiala (2009), Building motivation and sustainability into the prescription and recommendations for physical activity and exercise therapy: the evidence, *Physiotherapy Theory and Practice,* **25,** *5-6*, pp. 424-41.

W S Sander, D Eschelman, J Steele and C E Guzzetta (2002), Effects of distraction using virtual reality glasses during lumbar punctures in adolescents with cancer, *Oncology Nursing Forum,* **29**, E8–E15.

G Saposnik, R Teasell, M Mamdani, J Hall, W McIlroy, D Cheung, K E Thorpe, L G Cohen and M Bayley (2010), Effectiveness of virtual reality using Wii gaming technology in stroke rehabilitation: A pilot randomized clinical trial and proof of principle, *Stroke* published online May 27, 2010

E M Sluijs, J J Kerssens, J van der Zee and L B Myers (1998), Adherence to physiotherapy. In *Adherence to treatment in medical conditions* (L B Myers & K Midence, Eds), Harwood Academic, Amsterdam, Netherlands, pp. 363–382.

C D Takahashi, L Der-Yeghiaian, V Le, R R Motiwala and S C Cramer (2008), Robot-based hand motor therapy after stroke, *Brain,* **131**, pp. 425-37.

J H van der Lee, I A Snels, H Beckerman, G J Lankhorst, R C Wagenaar and L M Bouter (2001), Exercise therapy for arm function in stroke patients: a systematic review of randomized controlled trials, *Clinical Rehabilitation,* **15**, *1*, pp. 20-31.

H van Dijk, M J A Jannink and H J Hermens (2005), Effect of augmented feedback on motor function of the affected upper extremity in rehabilitation patients: a systematic review of randomized controlled trials, *Journal of Rehabilitation Medicine,* **37**, *4*, pp. 202-11.

R P S van Peppen, G Kwakkel, S Wood-Dauphinee, H J Hendriks, P J Van der Wees and J Dekker (2004), The impact of physical therapy on functional outcomes after stroke: what's the evidence? *Clinical Rehabilitation* 18(8), 833-62.

C Vincent, I Deaudelin, L Robichaud, J Rousseau, C Viscogliosi, L R Talbot, J Desrosiers and other members of the BRAD group (2007), Rehabilitation needs for older adults with stroke living at home: perceptions of four populations, *BMC Geriatrics,* **7**, *1*, pp. 20.

S LWolf, D E Lecraw, L A Barton, B B Jann (1989), Forced use of hemiplegic upper extremities to reverse the effect of learned nonuse among chronic stroke and head injured patients, *Experimental Neurology*, **104**, 125–132.

S Yamashita, K Iwai, T Akimoto, J Sugawara and I Kono (2006), Effects of music during exercise on RPE, heart rate and the autonomic nervous system, *Journal of Sports Medicine and Physical Fitness,* **46**, pp. 425–430.

©2010 ICDVRAT; ISBN 978 07049 15022

Remote monitoring and quantification of upper limb and hand function in chronic disability conditions

S H Brown[1], J Langan[2], K L Kern[3], E A Hurvitz[4]

[1,2,3]School of Kinesiology, University of Michigan,
1402 Washington Heights, Ann Arbor, Michigan, USA

[4]Department of Physical Medicine and Rehabilitation, University of Michigan,
325 E. Eisenhower Parkway, Ann Arbor, Michigan, USA

shcb@umich.edu, jlangan@umich.edu, klkern@umich.edu, ehurvitz@med.umich.edu

[1,2,3]*www.motorcontrol.umich.edu,* [4]*www.med.umich.edu/pmr*

ABSTRACT

This paper describes a convenient, home-based telerehabilitation system designed to improve upper limb and hand function in adults with cerebral palsy. The training program incorporates a variety of computer-guided sensorimotor activities such as unilateral and bilateral reaching, reaching and grasping, object manipulation, and tactile discrimination tasks. Quantitative measures of performance are uploaded to the laboratory after each training session for further analysis. Webcam monitoring of performance occurs periodically throughout the training period. Twelve adults with cerebral palsy completed a 40 min/day, five days/week training program over eight weeks. Temporal measures of performance indicated significant improvement in reaching and hand manipulation ability as well as improved tactile discrimination. Preliminary analysis of the time course of change revealed variable patterns within and across participants. The capacity to measure change throughout a training program provides an opportunity to investigate how learning occurs over time in chronic disability. Compliance was excellent with subjective reports indicating improvement in activities of daily living. Future development includes a fully automated system with stand alone modules which allow for customization of training protocols depending upon specific needs of the user.

1. INTRODUCTION

Repetitive practice of goal-directed movements has been shown to improve function in individuals with chronic upper limb impairment such as stroke (Langan and van Donkelaar, 2008; Taub et al., 1998; Wolf et al., 2007) and cerebral palsy (Gordon et al., 2005, 2006; Qiu et al., 2009; Taub et al., 2007). Typically, movement-based therapy programs involve several hours a day of task-specific training in an outpatient setting and with therapist supervision. These constraints may be cost-prohibitive for many individuals and may represent serious barriers to compliance.

Major advances in telecommunications technology have the potential to provide more efficient and effective therapies for individuals with motor disabilities. While the application of telemedicine in rehabilitation is still limited, several studies have demonstrated the effectiveness of upper limb training programs delivered via the Internet for individuals with chronic upper limb motor impairments such as stroke (Carey et al., 2007; Deutsch et al., 2007; Holden et al., 2007; Page et al., 2002; Piron et al., 2004, 2009). However, most such telerehabilitation programs require regular monitoring by or direct interaction with a rehabilitation specialist. Not all programs have the capability to quantify performance throughout the intervention period and thus rely on pre-and post-assessments performed in a clinic or research setting. Such information has the potential to assist in modifying training as performance improves and to identify patterns of performance change. Understanding how change occurs over time may provide valuable insights into the nature of movement-dependent functional improvements which may be used to develop more effective individualized training programs. The nature of training using telerehabilitation is quite variable with some telerehabilitation programs utilizing a broad range of arm and hand activities (Holden et al., 2008; Huijgen et

©2010 ICDVRAT; ISBN 978 07049 15022

al., 2008), while others have focused on variants of a single task such as visually guided arm movements (Piron et al., 2009) or tracking tasks (Carey et al., 2007). Related to this is the fact that explicit training of movement-related somatosensory function is almost invariably excluded despite the importance, for example, of tactile feedback in hand manipulation tasks (Byl et al., 2002).

In an attempt to address these issues, we have developed a home and Internet-based sensorimotor training program aimed at improving arm and hand function in chronic disability conditions (Brown et al., 2010). Our Upper Limb Training and Assessment (ULTrA) program incorporates several reaching and hand manipulation tasks which are performed in a home setting with only periodic supervision by a rehabilitation specialist. The current system provides quantitative information regarding task performance throughout the training period. The program was initially designed for adults with cerebral palsy (CP) since chronic childhood onset disorders such as CP have poor access to traditional, hospital or clinical-based services once school years are completed and the transition to adulthood is made. Some of the results related to arm reaching, interlimb coordination and hand function, have been recently published (Brown et al., 2010). In this paper, we will describe new findings related to more complex tasks involving reaching, grasping and moving objects, patterns of change throughout the intervention period for different tasks, and the effects of training on upper limb position sense.

2. METHODS

2.1 ULTrA Training Program

The ULTrA training system consists of a target reaching apparatus and several hand manipulation/discrimination modules. A laptop computer with user-friendly, interactive software is used to guide participants through a series of task-specific, sensorimotor training activities as well as warm up and cool down stretching exercises. For upper limb reaching tasks, movements are made to illuminated targets in the vertical or horizontal plane as specified by computer-controlled touch sensors embedded in an apparatus comprised of an upright and lower board (Fig. 1A). Unilateral, bilateral simultaneous, and bilateral sequential movements are performed depending upon the stage of training. Reach, grasp, and release tasks are also performed which require grasping and moving a cone-shaped object from one position to another on the horizontal aspect of the target apparatus and then returning the hand to a home target location. The ability to perceive and identify patterns using only tactile feedback is quantified using a custom-designed device into which the participant inserts his/her hand and scans different patterns of raised pins embedded along all four sides of a square plastic base (Fig 1B). Time-based, hand manipulation tasks include identification of computer-specified objects in the absence of vision (stereognosis), sliding or turning playing cards (Fig 1C), moving objects from one location to another using a pincer grip or modified chopsticks (Fig 1D), and manipulating metal chiming balls (Fig. 1E). Participants are required to identify the correct pattern from a series of possible patterns displayed on the computer in a preset amount of time. Sensor data related to reach duration, interlimb coordination and hand manipulation tasks are saved as text files to the laptop throughout each training session and then sent to the laboratory using either a TCP/IP protocol or a VPN connection. Webcams are used periodically throughout the training period to monitor and progress participants and to ensure that participants accurately record performance during the hand training tasks.

2.2 Upper Limb Training in Adults with Cerebral Palsy

Twelve adults diagnosed with CP (4 males, 8 females, 20.7 to 57.2 years) and with primarily unilateral upper limb involvement were enrolled in an 8 week training program using the telerehabilitation system described above. Participants were considered mildly to moderately impaired according to the Gross Motor Function Classification System (GMFCS), a 5-level scale where Level V represents the greatest functional impairment (McCormick et al., 2007; Palisano et al., 1997). Self-reports of the amount of upper limb use and the perceived quality of motion using the Motor Activity Log (Uswatte et al., 2006) indicated significant impairment according to a six point scale where 0 indicates the arm is never used and 5 indicates performance of the more affected arm is the same as the less affected arm. Training occurred for approximately 45 min a day, five days a week. Of the 12 participants, 10 ambulated independently, one used a walker and one used a motorized chair. All participants lived independently in the community and none were receiving therapy or medication related to upper limb function at the time of the study. All gave informed consent according to protocols established by the University of Michigan Institutional Review Board.

©2010 ICDVRAT; ISBN 978 07049 15022

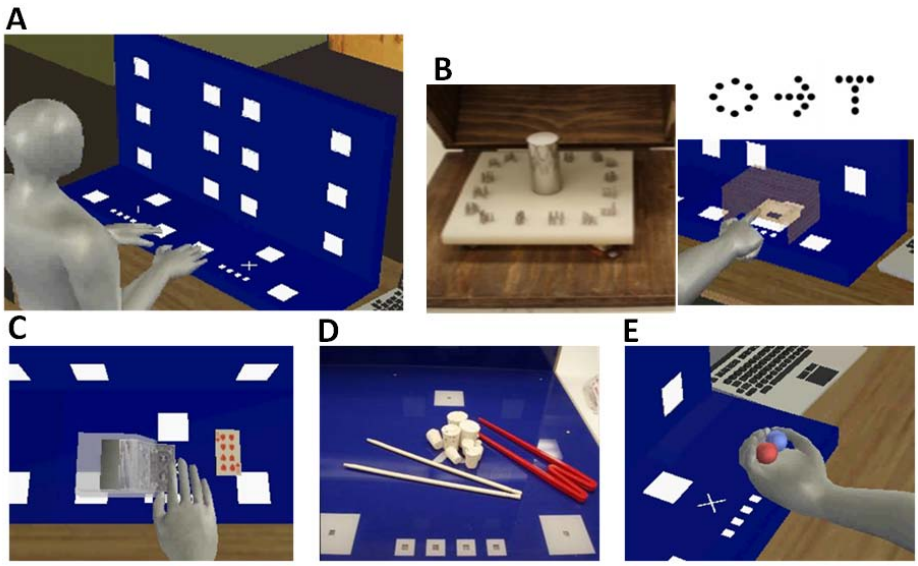


Figure 1. *Components of the ULTrA telerehabilitation program include an instrumented target reaching board (A), a tactile discrimination unit comprised of patterns of raised pins embedded in a plastic base (B), and several object manipulation tasks including card sliding/turning (C), moving objects with modified chopsticks(D), and rolling metal balls back and forth the palm of the hand (E).*

Table 1. *Participant characteristics (age, affected side, and functional assessment scores at baseline).*

Participant	Age yr	More Affected	Motor Activity Log Amount of Use	Motor Activity Log Quality of Motion	GMFCS
1	40.8	left	2.62	3.38	II
2	24.7	right	2.99	3.58	I
3	36.8	right	0.75	0.75	I
4	35.1	right	1.11	0.82	I
5	34.2	left	0.96	1.05	I
6	38.0	left	0.68	0.68	II
7	21.9	right	0.86	0.64	I
8	22.8	right	1.71	1.93	I
9	20.7	left	1.25	1.21	I
10	57.2	right	1.64	1.61	III
11	41.5	right	1.79	1.57	IV
12	32.5	right	0.5	0.39	I

Pre- and post-intervention clinical assessments included the Motor Activity Log, the Nine-Hole Peg Test, grip strength, and tactile spatial discrimination using JVP domes (Bleyenheuft and Thonnard, 2007). Upper limb proprioception using a position matching paradigm established by our laboratory (Goble and Brown, 2007, 2008; Goble et al., 2009) was also measured prior to and immediately following the intervention. Compliance was high with all participants completing 40 training sessions. Less than one percent of data were lost due to difficulties with data recording or transmission.

2.3 Data Acquisition and Analysis

Computer-determined reach locations were presented as illuminated square targets containing proximity sensors. When touched, the sensors generated timing information which was stored on the computer. For the hand manipulation and tactile discrimination tasks, participants used interactive software in order to record

©2010 ICDVRAT; ISBN 978 07049 15022

performance (e.g. number of cards turned). After each training session, data were transferred to the laboratory via the Internet. The effects of training on each dependent variable were determined using the nonparametric Wilcoxon signed rank test for paired comparisons.

3. RESULTS

3.1 Arm Reaching Performance

As previously reported, the ULTrA telerehabilitation program led to improved reaching performance in adults with CP. This was seen as a significant reduction in the time to perform reaching movements using the more affected arm during unilateral, bilateral simultaneous, and sequential movements (Brown et al., 2010). In more complex reach and grasp tasks, mean movement time across all participants decreased for both the transport (time to grasp and move an object) and release (time to release object and return to home position) components of the task. This is shown for the more affected hand in Fig. 2 during unilateral reaching. Based on data obtained from each training session, a novel feature of our training system, changes in performance were found to be variable both within and across participants for the reach/grasp task. Examples of performance change during the transport component are shown for three participants in Fig. 3. While movement time associated with object transport decreased for participants A and B by the end of the training, improvement occurred more quickly and with less session to session variability in participant A compared to participant B. The only participant to not show an improvement in this task (C) improved over the first three weeks, after which performance worsened and was quite variable.

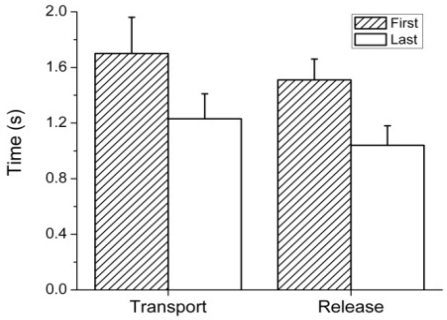


Figure 2. *Mean time required to reach, grasp and place an object (transport) and release and return to home position (release) during the first and last training session (more affected hand). Data are mean (+1 SE) for all 12 participants (p<.01).*

3.2 Object Manipulation

Several of the training tasks focused on manipulation of objects in the absence of vision (stereognosis), or using tools such as modified chopsticks. In the card sliding/turning task, all participants showed improvement over the course of training. This is illustrated in Fig. 4A for one participant performing card sliding (weeks 1-3) followed by card turning (weeks 4-8). The latter task was considered more challenging since forearm supination, frequently impaired in CP, was required to complete the task. When participants progressed from card sliding to turning, a marked reduction in the performance of both hands was often seen. This is illustrated in Fig 4A where a gradual improvement in performance of the more affected hand was seen over the remaining five weeks. The magnitude of change in the card turning task varied across participants as shown in Fig. 4B. In one of the 12 participants, performance declined after the training period and in another there was no change between the first and last training sessions. In the other 10 participants, the ability to grasp and turn cards improved by 10 to 250 percent.

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

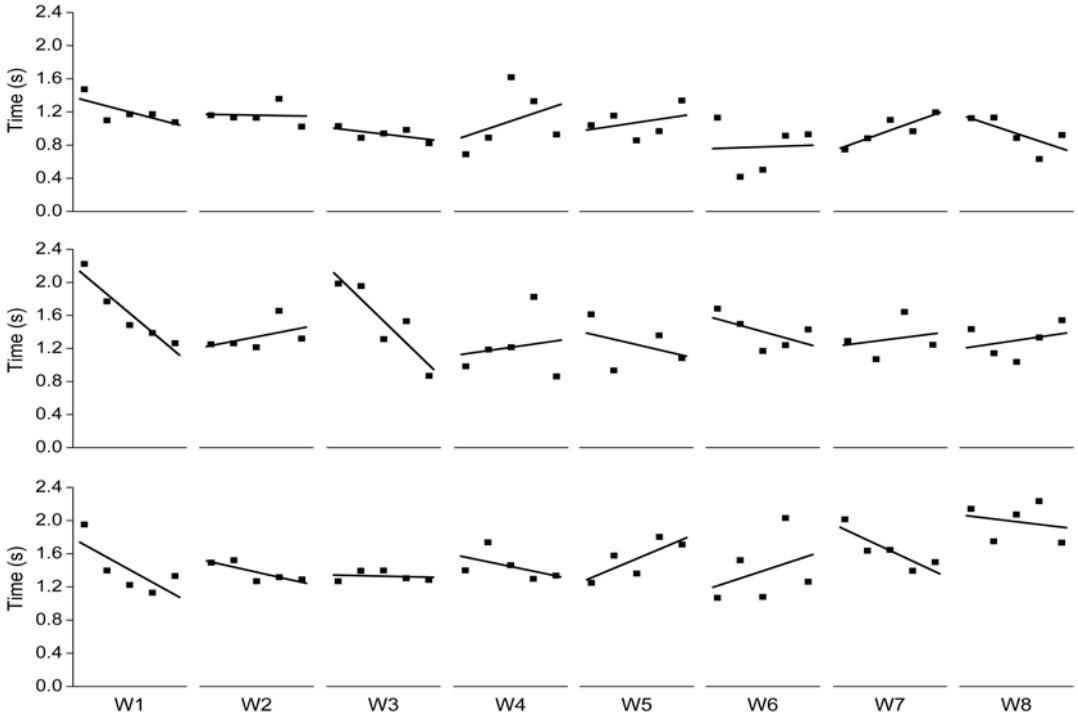


Figure 3. *Patterns of change in transport time for three participants (A-C). Each data point is the average from a single training session. Linear regression lines have been plotted for weekly data (W1-W8).*

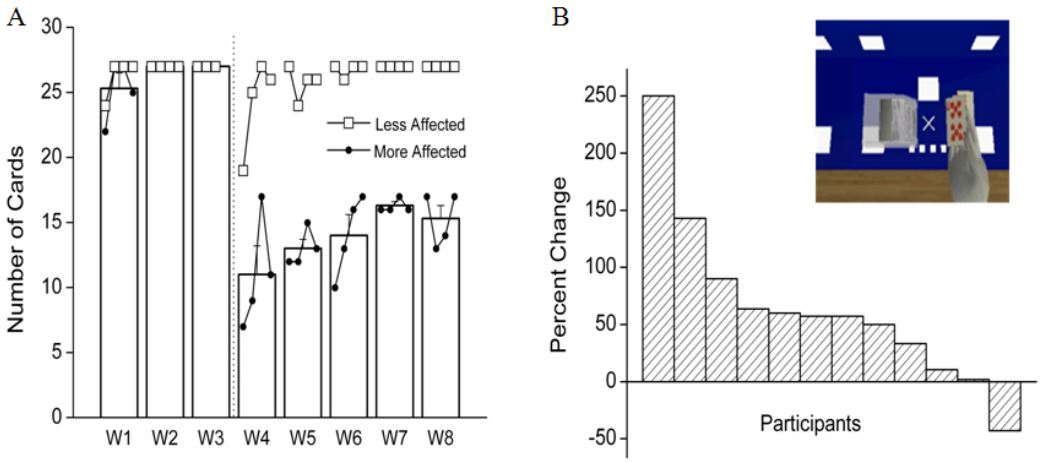


Figure 4. *The graph A shows the number of cards slid from the card holder during the first three weeks (W1-3) and turned during the remainder of the training period (W4-8) for one participant (open symbols – less affected hand, filled symbols – more affected hand). Each data point represents one training session. Bars represent average (+ 1 SE) weekly performance. Dashed line represents time when participant was progressed from card sliding to card turning. The graph B shows the percent change in card turning (image inset) for each participant ranked on the basis of the magnitude of improvement.*

©2010 ICDVRAT; ISBN 978 07049 15022

3.3 Movement-related Somatosensory Function

In addition to improved motor ability with training, there was also improvement in movement-related somatosensory function as evidenced by an enhanced ability to use tactile feedback in a pattern discrimination task and a reduction in errors associated with position matching tasks. In the tactile discrimination task at the beginning of training, mean accuracy in correctly identifying pin patterns with the more affected hand was 60 compared to 83 percent when using the less affected hand. However, mean accuracy significantly improved over the course of training to 71 percent (Brown et al., 2010). Slight gains were also noticed in the performance of the less affected hand with training but differences were not statistically significant. Examples of individual patterns of improvement in tactile discrimination over the course of training are shown in Fig. 5. While most participants made steady gains during the first week of training (W1), subsequent weekly performance was variable in most participants. In the examples shown, this is most notable in weeks 3-5. Despite week to week variability, however, all participants continued to improve in their ability to correctly identify pin patterns based only on tactile feedback.

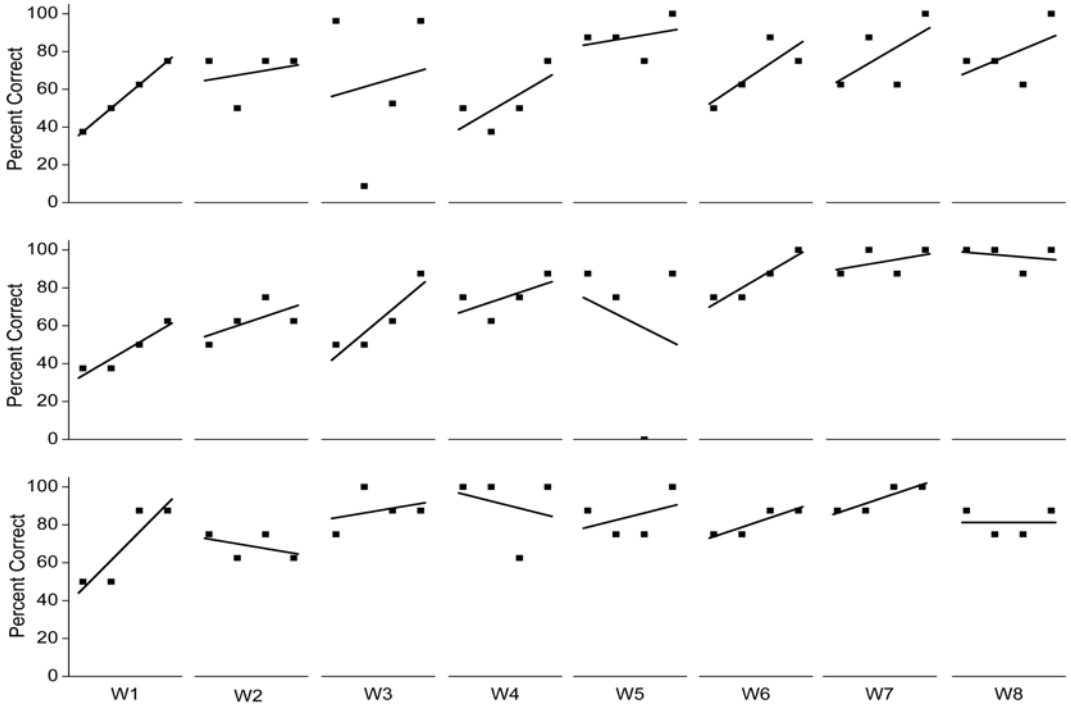


Figure 5. *Patterns of change in transport time for three participants (A-C). Each data point is the average from a single training session. Linear regression lines have been plotted for weekly data (W1-8). Data shown in A and B are from the same participants shown in Figure 3A and B.*

In addition to improvement in tactile discrimination with training, the ability to accurately reproduce elbow position improved in several but not all participants. In tasks where participants were required to actively match a passively determined elbow reference position with the same arm, errors were reduced in six of the 12 participants regardless of which arm was performing the matching task (Fig. 6). It should be noted that errors produced by the less affected arm prior to training were, for most participants, greater than those seen in non-disabled, age-matched individuals performing the equivalent task (approximately 3 deg, Goble and Brown 2008). The observation that matching errors decreased with training for some participants suggests that, even though position sense was not directly targeted as part of the training program, repetitive practice of goal-directed motor tasks may carry over to movement-related proprioceptive ability.

©2010 ICDVRAT; ISBN 978 07049 15022

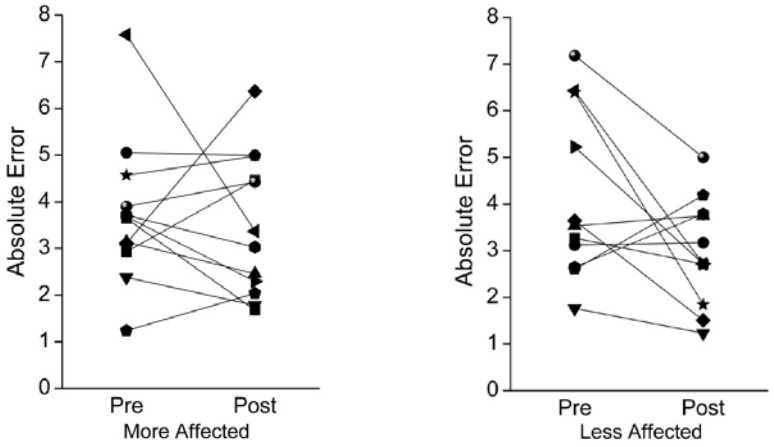


Figure 6. *Elbow position matching errors (deg) for the more affected and less affected arms. Each data symbol represents an individual participant.*

3.4 Functional Changes

Scores on both components of the Motor Activity Log improved following the intervention although gains were relatively modest (Brown et al., 2010). Evaluation of performance on the Nine-Hole Peg test, a measure of hand dexterity, was based on 10 participants in whom a mean improvement of 14.6 percent was observed during the post-intervention assessment. Grip strength of the affected but not the less affected hand also increased.

Participant feedback regarding the ULTrA program was positive even though experience using computers was quite variable. Indeed, our oldest participant who had never used a computer, purchased her own at the end of the program. Flexibility regarding when training occurred was viewed as a major factor contributing to the high degree of compliance observed in the study. Examples of comments from individual participants following completion of the ULTrA program include the following:

> "I became aware the arm is there and able to do (things)."
>
> "I was really surprised. I honestly didn't expect to see such a difference…I didn't gain more strength, but I gained control of my left hand."
>
> "I didn't even realize how my right side was deteriorating because I wasn't using it."
>
> "I can use both hands when I am dressing and driving the car… I always used my left arm to reach across and turn on the ignition key…. I don't do that anymore."

4. DISCUSSION AND FUTURE DIRECTIONS

These results demonstrate the effectiveness of a telerehabilitation system to improve upper limb function in adults with CP based on performance data obtained from various training tasks. Despite the chronic nature of the motor impairments, relatively short training sessions of less than an hour a day led to significant improvement in reaching and object manipulation ability as well as improved tactile discrimination. Only intermittent monitoring by a rehabilitation specialist was required during the training period which allowed participants to choose training times which were most convenient for them. The use of a computer-based system was not viewed as a barrier to compliance and many participants were eager to pursue similar training activities once the intervention was completed.

The ability to generate and transmit quantitative measures throughout the intervention period is a distinct advantage over most rehabilitation approaches which rely on pre- and post-assessments to evaluate change. Quantifying daily performance of adults with chronic upper limb deficits using sensorimotor tasks paves the way for many new avenues of research with the potential to further the field of rehabilitation for all individuals with upper limb deficits. Tracking a simple metric such as number of task repetitions may help us understand appropriate dosage for upper limb rehabilitation. A more complex use of the module data from

©2010 ICDVRAT; ISBN 978 07049 15022

individual training sessions is the examination of learning patterns in order to create algorithms that may suggest appropriate progression of the participant. As this technology advances, we believe that telerehabilitation has an imminent role in providing optimal healthcare.

Current research is now focused on adapting the system for use in chronic stroke including the development of grasp and pinch force devices with real-time visual feedback aimed at improving fine force control in both unilateral and bilateral hand force tasks. Automated versions of the tactile discrimination and card turning tasks are also in development. Long term goals will be to create easily portable, stand alone modules so that clinicians can tailor intervention programs to the specific needs of their clients. This technology would encourage a more proactive approach to maximizing function throughout a lifetime in chronic conditions by making rehabilitation more accessible and less resource intensive than other therapeutic interventions. The training system does not need to be limited to chronic stages of rehabilitation. It would also have applicability to acute and subacute stages where repetitive task training has demonstrated improvements in mobility (Kwakkel et al., 1999). This reinforces the idea that intermittent telerehabilitation interventions may be used to promote maximum function throughout a lifespan.

Acknowledgements: This study was supported by a grant to SB from the National Institute on Disability and Rehabilitation Research (H133G050151) and the National Institutes of Health, the National Institute of Child Health and Human Development, the National Center for Medical Rehabilitation Research (T32HD007422).

5. REFERENCES

Y Bleyenheuft, Thonnard JL (2007) Tactile spatial resolution measured manually: A validation study. *Somatosensory and Motor Research*. 24: 111-114

S H Brown, Lewis CA, McCarthy JM, Doyle ST, Hurvitz EA. 2010. The effects of internet-based home training on upper limb function in adults with cerebral palsy. *Neurorehabilitation and Neural Repair*

N Byl, Leano J, Cheney LK. 2002. The Byl-Cheney-Boczai Sensory Discriminator: reliability, validity, and responsiveness for testing stereognosis. *Journal of Hand Therapy* 15:315-30

J R Carey, Durfee WK, Bhatt E, Nagpal A, Weinstein SA, et al. 2007. Comparison of finger tracking versus simple movement training via telerehabilitation to alter hand function and cortical reorganization after stroke. *Neurorehabilitation and Neural Repair* 21:216-32

J E Deutsch, Lewis JA, Burdea G. 2007. Technical and patient performance using a virtual reality-integrated telerehabilitation system: Preliminary finding. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 15:30-5

D J Goble, Brown SH. 2007. Task-dependent asymmetries in the utilization of proprioceptive feedback for goal-directed movement. *Experimental Brain Research* 180:693-704

D J Goble, Brown SH. 2008. Upper limb asymmetries in the matching of proprioceptive versus visual targets. *Journal of Neurophysiology* 99:3063-74

D J Goble, Hurvitz, EA, Brown, SH. 2009. Deficits in the ability to use proprioceptive feedback in children with hemiplegic cerebral palsy. *International Journal of Rehabilitation Research* 32:267-269.

A A Gordon, Charles J, Wolf SL. 2005. Methods of constraint-induced movement therapy for children with hemiplegic cerebral palsy: Development of a child-friendly intervention for improving upper-extremity function. *Archives of Physical Medicine and Rehabilitation* 86:837-44

A M Gordon, Charles J, Wolf SL. 2006. Efficacy of constraint-induced movement therapy on involved upper-extremity use in children with hemiplegic cerebral palsy is not age-dependent. *Pediatrics* 117:E363-E73

M K Holden, Dyar TA, Dayan-Cimadoro L. 2007. Telerehabilitation using a virtual environment improves upper extremity function in patients with stroke. *IEEE Transactions on Neural Systems and Rehabilitation Engineering* 15:36-42

B C Huijgen, Volienbroek-Hutten MMR, Zampolini M, Opisso E, Bernabeu M, et al. 2008. Feasibility of a home-based telerehabilitation system compared to usual care: arm/hand function in patients with stroke, traumatic brain injury and multiple sclerosis. *Journal of Telemedicine and Telecare* 14:249-56

G Kwakkel, Wagenaar, RC, Twisk, JWR, Lankhorst, GJ, Koetsier, JC. 1999. Intensity of leg and arm training after primary middle cerebral artery stroke: A randomized trial. *Lancet* 354:191-196.

©2010 ICDVRAT; ISBN 978 07049 15022

J Langan, van Donkelaar P. 2008. The influence of hand dominance on the response to a constraint-induced therapy program following stroke. *Neurorehabilitation and Neural Repair* 22:298-304

S J Page, Levine P. 2007. Modified constraint-induced therapy extension: using remote technologies to improve function. *Archives of Physical Medicine and Rehabilitation* 88:922-7

L Piron, Tonin P, Trivello E, Battistin L, Dam M. 2004. Motor tele-rehabilitation in post-stroke patients. *Medical Informatics and the Internet in Medicine* 29:119-25

L Piron, Turolla A, Agostini M, Zucconi C, Cortese F, et al. 2009. Exercises for paretic upper limb after stroke: a combined virtual reality and telemedicine approach. *Journal of Rehabilitation Medicine* 41:1016-20

Q Qiu, Ramirez DA, Saleh S, Fluet GG, Parikh HD, et al. 2009. The New Jersey Institute of Technology Robot-Assisted Virtual Rehabilitation (NJIT-RAVR) system for children with cerebral palsy: a feasibility study. *Journal NeuroEngineering Rehabilitation.* 6:40

E Taub, Crago JE, Uswatte G. 1998. Constraint-induced movement therapy: A new approach to treatment in physical rehabilitation. *Rehabilitation Psychology* 43:152-70

E Taub, Griffin A, Nick J, Gammons K, Uswatte G, Law CR. 2007. Pediatric CI therapy for stroke-induced hemiparesis in young children. *Developmental Neurorehabilitation* 10:3-18

S L Wolf, Newton H, Maddy D,Blanton S,Zhang Q, et al. 2007. The Excite Trial: Relationship of intensity of constraint induced movement therapy to improvement in the wolf motor function test. *Restorative Neurology and Neuroscience* 25: 549-562

©2010 ICDVRAT; ISBN 978 07049 15022

Light Arrays: a system for extended engagement

D Wilde[1], A Cassinelli[2], A Zerroug[3], R J N Helmer[4], M Ishikawa[5]

[1,2,3,5]Ishikawa Komuro Laboratory, University Of Tokyo,
Hongo 7-3-1, Bunkyo-ku, Tokyo, JAPAN

[1]Department of Fine Art, Monash University,
900 Dandenong Rd, Caulfield East, Melbourne, VIC, AUSTRALIA

[1,4]Division of Materials Sciences and Engineering, CSIRO,
Henry Street and Colac Road, Belmont, Geelong, VIC, AUSTRALIA

[1]*d@daniellewilde.com*, [2]*alvaro@k2.t.u-tokyo.ac.jp*, [3]*alexis@k2.t.u-tokyo.ac.jp*,
[4]*Richard.Helmer@csiro.au*, [5]*Masatoshi_Ishikawa@ipc.i.u-tokyo.ac.jp*

[1]*www.daniellewilde.com*, [1,2,3,5]*www.k2.t.u-tokyo.ac.jp/members/index-e.html*
[4]*www.csiro.au/science/ps3xg.html*

ABSTRACT

We present the development vision of a range of interactive body-worn lighting systems for performance, play, rehabilitation and dis- or altered- ability support. The systems combine experimental and off-the-shelf technologies to arrive at outcomes that require and inspire extended physical and expressive engagement, and afford a range of different learning opportunities. We discuss the context and background, our aims and approach – mixing art, design and engineering methodologies. We then outline a number of scenarios of use and their relevance to ArtAbilitation. Our aim is to open up a dialogue with the ArtAbilitation community in the early stages, to generate collaborative interest and inform development.

1. INTRODUCTION

The *Light Arrays* extend the dynamic moving body with light to make visible the nuances and complexity of movement (fig.1). They were initially prototyped for *Swing That Thing: moving to move*, an investigation of how technological extension might poeticise experience through novel forms of physical engagement (Wilde 2010, 2007-2011). By incorporating lasers and LEDs into garments and modular fabric supports, the *Light Arrays* prompt wearers to interact and engage, through the lights, with body position and movement, as well with their dynamic position in space. Wearers of the initial prototypes report being inspired to move in new ways and to discover and explore their body through movement, in ways that differed from their usual methods, approaches and habits (Wilde, 2007). The experiments brought to light synergies across the authors' research, and provided the impetus for the current collaboration to extend this work into an interactive space. We present here the background research and context, as well as a number of development scenarios. Each scenario prompts a different kind of physical engagement, so different opportunities for learning movement and learning about and extending the bodies' expressive capabilities. From this perspective we discuss the relevance to ArtAbilitation.

2. CONTEXT & BACKGROUND RESEARCH

2.1 Context

The overarching research project, *Swing That Thing: moving to move*, is a doctoral investigation being undertaken at Monash University and at the CSIRO. The *Extended Light Arrays* brings this research to the University of Tokyo. The three contexts differ considerably – a Department of Fine Art in a University Faculty of Art and Design and a Government Scientific and Industrial Research Organization, both in Australia, and a Department of Creative Computing in a University Faculty of Engineering in Japan. The research in each of these contexts is driven by different concerns, constraints, challenges, opportunities and requirements regarding outcomes and reporting. The research is also being undertaken in different social and cultural contexts and languages – in Japan, for example, the work is being undertaken in a combination of

©2010 ICDVRAT; ISBN 978 07049 15022

French and English, in the broader context of Japanese. In Australia, the work takes place in English. The authors thus bring cross-cultural, as well as multi- and cross-disciplinary experience. Collectively they have extensive experience in fine art, materials science, engineering, garment design and construction, performance development, and the design, implementation and evaluation of interactive systems for a range of applications. The collaborators' complementary, as well as common skills, lead them to approach similar questions with different perspectives. This leads to rich outcomes informed by a broad knowledge base, and is an integral aspect of the *Extended Light Arrays* project. Short descriptions of background research perspectives follow, to enable a clear understanding of our approach.

Figure 1. *Light Arrays [Wilde, 2008].*

2.2 Background

2.2.1 Swing That Thing : moving to move is practice-based research guided by Art and Design ideation techniques and intuitive processes. The investigation sits within the broader field of Interaction Design, and is being undertaken in a mixed context of Art, Design, Science & Technology Research. Outcomes evolve from a common design intent: 'to move the body through real and virtual extension'. Extending the body mechanically, gesturally and sensorially can encourage people to move in extra-normal ways, so view and experience their bodies from perhaps hitherto unknown perspectives. This opens up a free-form expressive space that can provide a rich playground for self-expression, as well as surprising opportunities to observe how people learn in, through and about their bodies. It affords insight into how our bodies can move and what this feels like; individual body-centric learning preferences; and the idiosyncratic nature of personal, corporeal expressiveness. This research seeks to engage both body and imagination, and blur the boundaries that separate art from everyday life. As discussed in (Wilde et al, 2010) many applications in the area of rehabilitation and disability have been identified for the different praxis outcomes. Throughout the research, the experiential potential of the body and the imaginative capacity of people are foregrounded, guided by the belief, and experience, that doing so can provide radically different opportunities for engagement than coming from more pragmatic, technologically- or functionally- driven perspectives. A direct result of this approach has been extended engagement, and repeated requests for more opportunities to use the devices. This desire for continued and extended engagement may be beneficial in abilitation contexts where maintaining engagement has proven challenging.

2.2.2 CSIRO, Advancing Human Performance. At the CSIRO, researchers are developing wearable interactive textile systems and garments for a range of applications in sport, entertainment and health. The main driver is to move from traditional hard electronics to a combination of hard and soft electronics in garments and on the body, with the knowledge that new devices can enable new information, experiences and engagement in new environments. The group develops textile based wearable technologies for sensing limb movement, pressure, impact, moisture, and the electrical activity of the body using advances in new materials that when combined with digital infrastructure enable new mobile measurement and information for feedback in diverse environments. The focus is on empirical validation of the utility and value of the devices that are developed. The work is not only "good fun" but is socially beneficial and can demonstrate devices that have a tangible, real life benefit.

©2010 ICDVRAT; ISBN 978 07049 15022

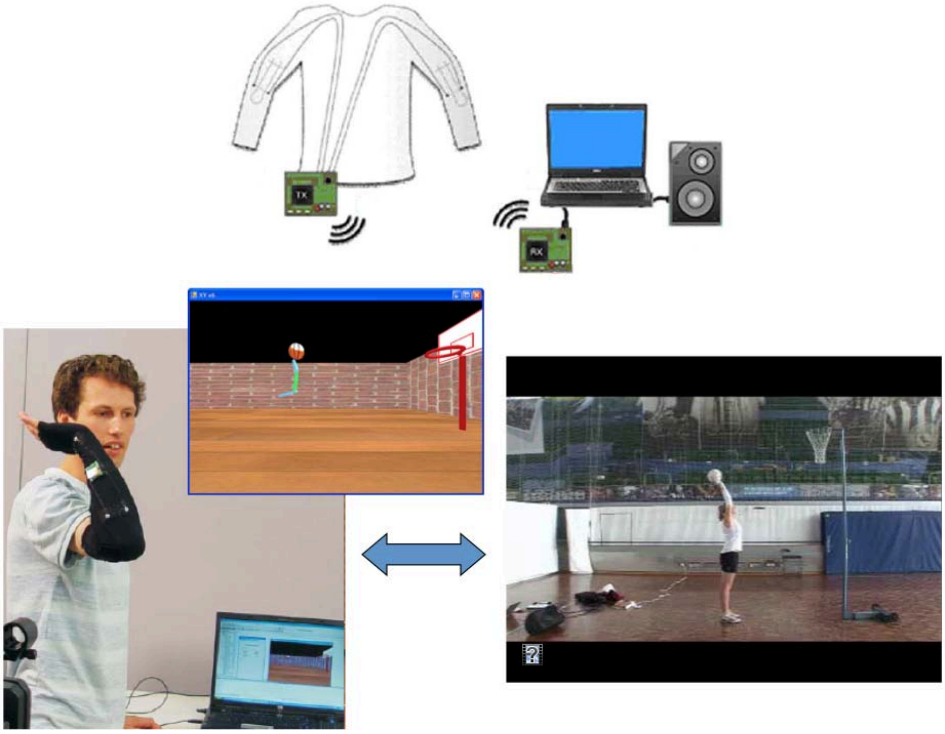


Figure 2. *WISh Wearable Instrument Shirt. A mobile system that uses music to support body-centric learning in real world environment.[Helmer, et al., 2010]*

One of the sensors being used in the *Extended Light Arrays* project was developed by CSIRO to measure elbow and wrist flexion, to link elite skill to novice development through a wearable device, by combining music with biomechanics for skill development, focus and engagement. The device (fig.2) uses rhythm to promote temporal and spatial awareness of a throwing skill. Participant groups include elite athletes and novices and, more recently a participant with Cerebral Palsy. The work with the able-bodied participants has allowed for improvement in skill through prescribed use of the device, without direct input or presence of a coach or skilled mentor. It has also included benchmarking to other measurement systems. (Helmer et al., 2008, 2010) We are interested to observe how these outcomes map onto the disabled participant, who has very different needs. For *Swing That Thing…* the same sensor has been adapted to measure flexion at the waist (Wilde 2009), for use by able-bodied and disabled participants.

The CSIRO system is mobile. It operates independent of architecturally based infrastructure, allowing field work to be undertaken both indoors and outdoors, in real-world settings, far from the lab. This represents a major advantage over camera vision techniques, and we believe is highly relevant to people with different physical and communicative disabilities, who may feel more comfortable, and thereby more able to undertake certain tasks and express themselves freely, in familiar environments.

2.2.3 Meta Perception at the University of Tokyo. The Meta Perception Group foreground culture and the body as they investigate how to extend perception through technological mediation. Most research outcomes are developed for cultural contexts, and result in technologically innovative solutions, and sometimes significant advances in engineering. Increasingly the group has become interested in wearable works. The *Haptic Radar,* for example, is a spatial augmentation device for the visually impaired. (Cassinelli et al., 2006a,b) (fig.3). It is a modular device that allows the wearer to perceive and respond to spatial information using haptic cues in an intuitive and unobtrusive way. The system is composed of an array of invisible lasers that simulate "optical-hair modules". Each laser senses range information, which it transduces as a vibro-tactile cue on the skin below. It thereby operates as a kind of cellular cilia (insect antennae), or in the same way as the specialized sensory hairs of mammalian whiskers. The first prototype of the *Haptic Radar,* a headband that provides the wearer with 360 degrees of spatial awareness, has had positive reviews in proof-of-principle experiments. Further testing, with a sample of 50 blind users, has since been undertaken and results are currently being analysed[1]. This system complements the *Light Arrays* systems outlined here as,

[1] In collaboration with Eliana Sampaio, Laboratoire Brigitte Frybourg, Conservatoire National des Arts et Métiers, France: *http://handicap.fr*

©2010 ICDVRAT; ISBN 978 07049 15022

rather than reflecting the wearer's movement onto space, the *Haptic Radar* reflects the proximity of space, dynamically, onto the wearer.

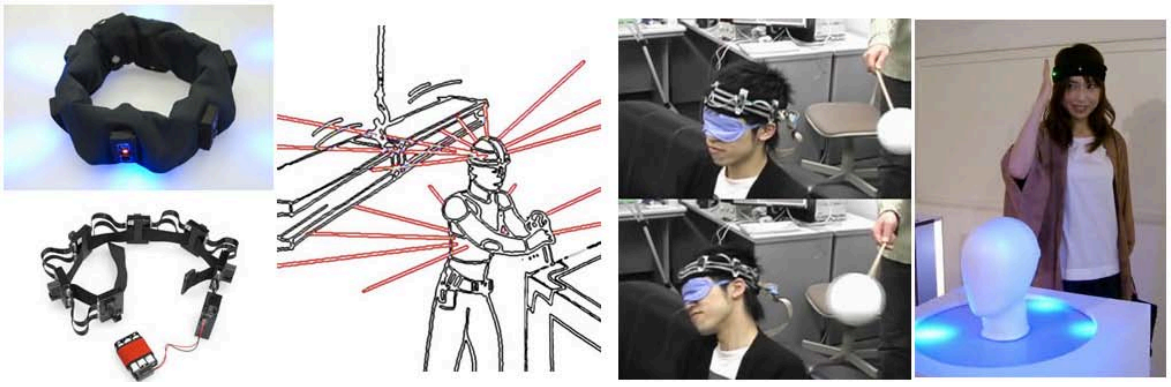


Figure 3. *Haptic Radar / The Extended Skin Project [Cassinelli et al., 2006]*

3. RELATED WORK

Light has long been used as an exploratory tool to gain insight into body dynamic. Historic examples include Marey and Muybridge's photographic locomotion studies (Marey 1994; Muybridge 1979). Motion Capture provides a contemporary equivalent. (for an overview see Furniss, 2000). Merce Cunningham said that motion capture technology allows him to "see movement in a way that was always there – but wasn't visible to the naked eye" (Schibsted, 1996). The *Light Arrays* do the same, but in real time, independent of architecturally based infrastructure, so potential applications and scenarios of use are broader. Though intangible, the *Light Arrays* echo Rebecca Horn's early body extensions (Zweite et al. 2007), and Hussein Chalayan's fashion collection, *Readings* (Chalayan and Waldemeyer 2008). *Readings* does not provide information on body motion, it does, however, provide a startling example of the aesthetic power of pairing lasers with the body. Hewitt-Parsons speaks of the advantages of tactile media aids to maintain and strengthen motor skills and eye/hand co-ordination, to simulate the sensory system and improve visual-spatial awareness (Hewitt-Parsons 2006). The *Light Arrays* are intangible, but visible. We are curious to see if they will lead to similar or complementary outcomes.

The co-authors of this paper collectively have a large body of artistic and scientific research into worn technologies, extension and the use of lasers for physical engagement. See (Wilde 1997-2011) for a range of approaches to extension, as well as *Sticky light* and *scorelight*, dynamic laser systems that turn any object, including the body, into a light- or optical- 'pickup' (Cassinelli at al., 2008a,b). Also of relevance is Manabe's *Face Visualiser*, which uses Masaki Teruoka's myoelectric sensing system to turn the face into an optical pickup head (Manabe 2008). We may collaborate with Manabe, to use this system to translate muscle movement into light. (see 5.1.3)

4. AIMS & METHODOLOGIES

A number of different light-based, body-worn systems for physically engaged, expressive interaction are being implemented. These are outlined in Section 5. The development process in each case is an iterative, reflective process guided by Art and Design ideation techniques and intuitive processes. We begin with very basic prototypes, which we develop in constant negotiation with a broad a range of participants. We work with highly skilled performing artists and people with different physical challenges and abilities. By covering extreme case scenarios (Moggridge 2006) we hope to better understand the limitations and affordances of the different approaches, as well to make devices that work for different bodies. Our intention is to arrive at systems that are physically and imaginatively engaging, for a range of contexts and abilities.

5. PROPOSED SYSTEMS & SCENARIOS OF USE

5.1 Overview

We present here three different approaches. In each case the desire is to bring attention to the body by extending it with light, to support playful physically engaged exploration. Cultural artefacts including performances, objects and garments for a range of contexts are being developed for the general public, as

©2010 ICDVRAT; ISBN 978 07049 15022

well as specific user groups. These form part of the research process and are also considered research outcomes. Importantly, within this process, we will work with disability groups to understand and incorporate their needs and tailor the devices as appropriate. Considerations include fit (being able to put the garment or support on may be a major challenge for some people), feel (how comfortable the device is to wear plays a crucial role in its use), and also the broader aesthetics of the interaction. It is important that the outcomes are engaging. It is also important that they bring the wearer, in new ways, to knowledge about their bodies. The reasoning behind this is discussed below.

5.1.1 Light Arrays. This work builds upon the original *Light Arrays* prototypes. By extending the body perpendicularly with rays of light we can visually magnify the minutae and complexity of movement. This has a number of applications. It may be particularly useful for participants with vestibulaire disorders, for example, if the lasers extend from the waist. By observing the array of dots on the walls surrounding them, the participant would be able to identify if they are standing upright (in which case the dots would be aligned horizontally) or if and how they may be off balance (in which case the light array would be tilted).

In a very different application, the system may be used to inspire people to engage their bodies through imaginative tasks. For example, a treatment for leg ulcers involves compression bandages and regular movement of the ankle to maintain circulation. If circulation is not maintained treatment fails, yet it is challenging to get people to regularly and randomly move their ankles over extended periods, so success rates remain low. By attaching a laser to the base of the foot, the patient could be asked at regular intervals to draw objects, write lists or otherwise or map out things that they are interested in or passionate about. Tasks could include: writing the names of their grandchildren; mapping out their favourite walk through town; the relationships between their friends; the plants in the garden; the tools in the shed; etc., etc., or they could simply be asked to follow the contours of the room with the laser; or trace out different objects in the surrounding environment; to solve complex mathematical equations; to draw pictures or to write out musical scores. The role of the health practitioner would be to assist the patient in finding tasks that resonate for them emotionally. Our hypothesis is that if the task resonates emotionally for a patient, they will be more likely to engage over an extended period. In the case of patients with leg ulcers, this enhanced engagement would lead to beneficial results in their healing process.

We are currently developing a robust and elegant system to be tested with groups of people with physical and communicative challenges. We aim to fully explore the potential of this very simple application of technology to the body, to examine if and how the current positive outcomes might map onto people with different disabilities, and whether or not our hypotheses stand. Outcomes with able-bodied participants include discovering new things about their bodies, learning how to make different kinds of movement, and being inspired to explore and investigate their potential for movement in ways that are unexpected, novel and stimulate extended and unfamiliar abilities.

Figure 4. *In-visible garments for two – mapping movement and posture of one participant onto another participant's "skirt".*

5.1.2 An in-visible garment. A skirt made with lines of light. This garment has a number of iterations that each behave in different ways, and thereby support different kinds of physical interaction. In each case, the relationship between waist, hip and torso is measured and used to control laser position, rendering the interface ideal for hip-focused rehabilitation, or any kind of therapeutic care where increasing lower back flexibility is desirable. Technically, the interface consists of an undergarment that measures flexion at the waist (using textile sensors discussed in 2.2.2), as well as a wide hip-belt that supports servo motors, laser

©2010 ICDVRAT; ISBN 978 07049 15022

modules and an integrated circuit that uses the input from the undergarment to infer body position and thereby inform laser position. In their neutral state, the lasers point downwards, angling out from the hip to suggest the presence of a striped A-line skirt (the lines of light from the lasers forming the stripes, (see fig 4). The garment is being programmed with a number of playful behaviours such that the movement of the lasers echoes, extends and exaggerates the "natural" or expected movement of the light based "fabric" as the wearer of the "in-visible" skirt moves. The skirts provide a context in which to playful explore movement.

A two-person version is being developed to allow pairs of people to play and interact with each other through their skirts. By mapping one person's movement in playful and exaggerated ways onto the other person's "skirt" (fig 4), we hope to encourage playful and extended physical exploration in a more social setting. In such a scenario, learning about body movement would be a shared activity. This may further support the greater ease in communication that has been seen to result from physical engagement. (Gallagher, 2005)

5.1.3 Trace Memory Garment. In a very different use of light, we propose a system that measures muscular tension and physical pressure, and translates this data into light intensity and duration, on the body, at the point of tension or contact. The proposed system will use myoelectric sensing to measure muscular stresses, and will also leverage the natural optical phenomenon known as frustrated total internal reflectance (FTIR) (Gettys et al., 1989) to mechanically translate contact or pressure into light. Visually representing physical sensations where they occur may be of particular relevance to people with damaged, low- or mis-functioning somatosensory systems. It provides an alternative modality through which to access tactile and proprioceptive information. It may also provide learning opportunities for people who have problems with physical proximity and expression. This system provides radically different experiences from, for example, haptic systems, that bring the attention through the body to a screen, or through a screen and haptic feedback device to the body. In a way we are proposing a collapse of the traditional body-screen paradigm to render the body itself as screen.

5.2 Summary

Our expertise is not in disability research, so our suppositions in this area risk being naïve. Nonetheless we see many applications for this work in disability and rehabilitation. The scenarios of use we are proposing include artistic applications for performance and play; engaging rehabilitation patients, physically, through their imaginations – having patients draw or write things through their bodies (Lieberman et al., 2009; Wilde, 2009). We also see broad application with people who have underdeveloped or damaged proprioceptive abilities and/or communicative issues. Extended physical exploration seems to lead to greater self-knowledge, which in turn may lead to extended abilities, enhanced empathic relationships with the self, and thereby greater ease in communication (Gallagher 2005, especially pp. 144-146). We believe this to be of value in many abilitation contexts.

6. DISCUSSION

The proposed devices provide free-form expressive spaces that encourage different qualities of attention: on the task at hand, the actions and gestures of the body, or on the results of those actions as presented through the laser extensions. By focusing on the results of their actions, rather than on the actions themselves, participants may be able to enhance their ability to learn physical skills (Helmer et al., 2008). Bringing focus back to the body can enhance self-awareness. The resulting increase in physical dexterity and range, may also impact positively on the individual's ability and ease communicating (Gallagher, 2005). In related research, participants have been prompted by the affordances of wearable interactive systems to explore and test the possibilities for action in their body, (Wilde, 2010) and thereby engage in a process of creating and reflecting on new modes and patterns of bodily experience, facilitated by the interaction between body movement and the effects of the technology.

The openness of *The Extended Light Arrays* allows for the generation of activities, pitched at an appropriate level, to target specific outcomes. Practitioners will be able to work with each participant to design individual programs, and guide them as they invent their own games. Benchmarks are set on an individual, case-by-case basis. The devices may thus be used by people with different challenges and unconventional abilities to achieve a range of results at a speed or pace appropriate to the individual. Tasks can also be designed for personal idiosyncrasies. Outcomes provide access to the inherent aesthetics of different movements, as well as novel ways of seeing and experiencing the body. Those with low- or unconventionally-functioning bodies may be encouraged to use the neglected parts of their body willingly,

©2010 ICDVRAT; ISBN 978 07049 15022

inspired by the expressive potential of the light extensions as their attention shifts away from their bodies to the aesthetically refined results of their actions. Doing so may allay further muscular degeneration through extended engagement and lead to greater physical control. Highly positive results have been seen, for example, when dance is practiced by people with Cerebral Palsy (see Tamar Rogoff's work with Gregg Mozgala[2]). The Extended Light Arrays System provides an alternative to dance, whereby participants can engage expressively through their bodies in a multitude of ways.

Gibson (1977) writes of perception leading to an awareness of affordances. If we consider that perception is a skilled activity (Varela et al. 1991), turning attention to and through the body by augmenting perception may lead to opportunities to learn new somatic techniques and increase specific skills and/or range of movement. Nöe (2005) insists that "perceiving is something we do", and that perceptual awareness depends on the perceiver's having "sensorimotor knowledge" – an implicit understanding of the way sensory stimulation varies with movement. By providing novel opportunities to experience in and through the body, and gain insight into the body's capacities and affordances when contexts for engagement are shifted, we hope that people will be able to develop their sensorimotor knowledge and skills. We believe this is relevant to people with many different physical abilities and challenges and look forward to better understanding how to explore this premise.

There are a number of challenges inherent in this research project. To begin with, we have a limited amount of time and the ideas emerging from the collaboration are incredibly rich. We hope to find research partners who are interested in assisting us with user testing and analysis. In particular we would like to work with groups of people who have a range of disabilities to explore and test the relevance of our outcomes, and also impact development. Finally, we are also looking for disabled groups and organizations interested in exploring the creation of cultural artefacts.

7. CONCLUSION

This research crosses many discipline boundaries and requires expertise in a broad range of areas. We believe it will result in innovations that are relevant to a number of research communities, as well as to a diverse public, most important to those with physical and communicative challenges. We invite collaborative interest.

Acknowledgements: Our thanks to the participants. Wilde's presence in Tokyo is made possible through an Australian Prime Minister's Australia Asia Endeavour Award. For supervision of her doctoral research, she would like to thank Dr Richard Helmer and her principal supervisor at Monash University, Dr Melissa Miles.

8. REFERENCES

A Cassinelli, D Manabe, Y Kuribara and A Zerroug (2008a), *scoreLight* Available from http://www.k2.t.u-tokyo.ac.jp/perception/scoreLight/index.html.

A Cassinelli, K Yusaku, S Perrin and M Ishikawa (2008b), *Sticky Light*. Available from http://www.k2.t.u-tokyo.ac.jp/perception/StickyLight/

A Cassinelli, C Reynolds and M Ishikawa (2006a) Augmenting spatial awareness with Haptic Radar. *IEEE Proc. Intl Sympos. Wearable Computers (ISWC)*. Montreux, pp. 61-64.

———. *Haptic Radar / Extended Skin* (2006b). Available from http://www.k2.t.u-tokyo.ac.jp/perception/HapticRadar/index-e.html.

H Chalayan and M Waldemeyer (2008), *Readings*. Available from http://www.waldemeyer.com/laser.html

M Furniss (2000), Motion Capture: An Overview. *Animation Journal* 8, 2, pp. 68-82.

S Gallagher, (2005) *How the Body Shapes the Mind.* Oxford University Press, USA.

E W Gettys, F J Keller, and M J Skove (1989), *Classical and Modern Physics*. McGraw-Hill, New York.

J J Gibson (1977), The Theory of Affordances. In *Perceiving, Acting, and Knowing*, Eds. Robert Shaw and John Bransford, University of Minnesota Center for Research in Human Learning. Hillsdale, Erlbaum, New York, London

[2] *http://www.nytimes.com/2009/11/25/arts/dance/25palsy.html*

©2010 ICDVRAT; ISBN 978 07049 15022

R J N Helmer, M A Mestrovic, D Farrow, S Lucas and W Spratford (2008), Smart Textiles: Position and Motion Sensing for Sport, Entertainment and Rehabilitation. *Advances in Science & Technology* 60 (Smart Textiles), pp. 144-153.

R.J.N. Helmer, D. Farrow, S.R. Lucas, G.J. Higgerson, I. Blanchonette (2010), Can interactive textiles influence a novice's throwing technique? *Procedia Engineering* (The Engineering of Sport 8 - Engineering Emotion) 2, 2, pp. 2985-2990

S Hewitt-Parsons (2006), Unintentional Therapy, Unexpected Results: My artistic life to this point. *Proc. ArtAbilitation*, edited by A. L. Brooks. Esbjerg, Denmark, pp. 91-96.

Z Lieberman, J Powderly, E Roth, C Sugrue, T Quan and T Watson (2009), *The EyeWriter*. Available from http://www.eyewriter.org/.

D Manabe (2008), *Face Visualiser*. Available from http://www.daito.ws/works/smiles.html

E-J Marey (1994), *Etienne-Jules Marey*, (Photo Poche). Centre de la Photographie, Paris.

B Moggridge (2006), *Designing Interactions*. MIT Press, Cambridge.

E Muybridge (1979), *Complete Human and Animal Locomotion : All 781 Plates from the 1887 Animal Locomotion : New Volumes 1-3 (Reprints of original volumes 1-4, 5-8 and 9-11)*. Dover, Mineola.

A Noë (2005), *Action in Perception*, MIT Press, Cambridge, MA

E Schibsted (1996), LifeForm. *Wired*, October 1996, pp. 172-173.

F Varela, E Thompson, E Rosch (1991), *The Embodied Mind*, MIT Press, Cambridge, MA

D Wilde (1997-2011), http://daniellewilde.com

——— (2007-2011), *Swing That Thing: moving to move.* Available from http://daniellewilde.com/dw/SwingThatThing.html

——— (2010), Swing That Thing: moving to move : extending our poetic and expressive potential. *Second Nature International Journal of Creative Media.* 2,1, pp.164-197

——— (2009) *hipDrawing*. Available from http://www.daniellewilde.com/dw/hipDrawing.html

———（2008a) Extruding the Body with Light to Make Visible the Spatial Relationships inherent in Gesture and Posture. *Workshop on Pervasive Visual, Auditory and Alternative Modality Information Display. Proc. Intl Conf. on Pervasive Computing*. Sydney.

——— (2007) *Light Arrays*. Available at http://www.daniellewilde.com/dw/lightarrays.html

D Wilde, R J N Helmer and M Miles (2010), Extending Body & Imagination : moving to move. *Proc. ICDVRAT with ArtAbilitation* Viña del Mar/Valparaíso, Chile

A Zweite, K Schmidt, D von Drathen, and R Horn (2007), Rebecca Horn, Drawings, Sculptures, Installations, Films 1964-2006, *Exhibition Catalogue*. Hatje Cantz, Berlin.

©2010 ICDVRAT; ISBN 978 07049 15022

Warriors' Journey: a path to healing through narrative exploration

J F Morie, E Haynes, E Chance

Institute for Creative Technologies,
University of Southern California
12015 Waterfront Drive, Playa Vista, CA, USA, 90094

{*morie, haynes, chance*} *@ict.usc.edu*

www.ict.usc.edu

ABSTRACT

The Warriors' Journey is an interactive narrative experience that is part of the online, virtual world healing space of the Coming Home Project (www.cominghomecenter.org) at the University of Southern California's Institute for Creative Technologies. This project is exploring new ways to reach veterans who are returning from recent conflicts and who often have mental health issues or difficulty fitting back into their home communities. We are looking at the affordances of online 3D virtual worlds to address some of the issues that may prevent or deter veterans from getting the help they need. We are exploring the use of specific therapies within the virtual world space, as well as social and enrichment activities designed around the needs of this group. *The Warriors' Journey* is one such activity that engages participants in stories to emphasize and reinforce common ideals of honorable warriors throughout history. After experiencing these stories, participants are then encouraged to construct their own warrior's story within the Coming Home space. It is hoped that such activities may help contribute to a more positive sense of self-esteem, a restructured life narrative, and a feeling of control over the stresses incurred during their service to their country.

1. INTRODUCTION

"Wounded people may be cared for, but as storytellers, they care for others. Their injuries become the source of the potency of their stories." … "Because stories can heal, the wounded healer and wounded storyteller are not separate, but are different aspects of the same figure." (A Frank, 1997)

The Coming Home Project at the University of Southern California's Institute for Creative Technologies (ICT) is exploring new ways to bridge the divide between returning veterans who need mental health services and those who actually receive that help. One in five service members from recent conflicts are estimated to be suffering from PTSD or major depression (RAND 2008). The military takes this problem seriously and has implemented many programs to assist returning troops, yet many veterans who need help are not seeking it. A 2008 study found that only about half of those who met the criteria for PTSD or major depression sought help (RAND 2008). Furthermore, many of the veterans who do go for help eventually drop out of their treatment programs. A 2010 study published by researchers from the Veterans Administration and the University of California concluded that "the vast majority of OEF[1] and OIF[2] veterans with new PTSD diagnoses failed to attend a minimum number of mental health sessions within a recommended time frame required for evidence-based PTSD treatment" (Seal et al. 2010). In addition, 41% of patients getting their care through the V.A. reside in sparsely populated areas and do not have access to appropriate medical facilities within a reasonable distance (Levin 2007).

ICT is looking at the affordances of online 3D virtual worlds to address some issues that may prevent or deter veterans from getting the help they need. Among these issues are: the stigma of being considered weak, which may negatively affect their careers (Rand 2008), distance from full service care facilities due to the preponderance of soldiers from rural areas (Levin 2007), and most critically, soldiers not recognizing that they even need help (Rand 2008). We believe that different affordances of the virtual world can be used to

[1] OEF: Operation Enduring Freedom
[2] OIF: Operation Iraqi Freedom

©2010 ICDVRAT; ISBN 978 07049 15022

mitigate each of the aforementioned issues in the following ways: In a virtual world, one interacts by means of an avatar, a 3D representation that can be given a fictitious name and persona (mitigating the stigma concern). The virtual world can be accessed from anywhere there is a computer and an internet connection (allowing for more resources to reach the widely dispersed veterans), and can encourage self reflection by providing tools that help identify the signs of mental health issues. Additionally, another benefit of virtual worlds is a sense of familiarity because virtual worlds are similar to multi-player games. This helps to provide an enjoyable and engaging platform designed not only for fun, but also for the formation of social-support groups that are attractive to "Digital Natives" – those in the age group of most soldiers – who grew up on games, computers and the Internet.

We believe that this sense of familiarity with virtual worlds combined with a robust graphic environment, use of customizable 3D avatars, and the broad possibilities offered by a functional scripting language operant in this platform will help the Coming Home Project fulfill its goal of creating engaging activities in the online world that encourage repeat visits. It is for these reasons that we chose the Second Life (SL) virtual world as our platform. Additionally, it is also free to users who simply want to access content.

One activity we have developed for these "Digital Natives," and the focus of this paper, is a compelling interactive narrative in Second Life, available within a larger veterans' healing space, which we have been constructing. This narrative-based activity was designed to address our target audience – returning war veterans – by showcasing stories of honorable warriors throughout history in order to help mitigate the loss of self-esteem and self-worth that some soldiers experience as a result of mental illness (Wong and Cook 1992). In focusing the stories on warriors, we have set a context with which each veteran can connect, given the strong ideals they adhere to as part of their modern warrior culture. Three essential overlapping core values common to all branches of today's Armed Services are courage, honor, and selfless service/duty. We therefore chose stories about historical warriors that reinforce these key concepts. Our long-term goal is to have this activity (along with others) provide therapeutic value that aids veterans in their successful post-deployment reintegration, by helping them rebuild or reinforce a stronger and more positive sense of self in the civilian world.

To make this story experience truly interactive, we also included an embodied conversational agent (ECA) that could answer any questions the participant might have about the story being experienced.

2. THEORETICAL BACKDROP: THE POWER OF NARRATIVE

Narrative approaches have had a place in therapeutic activities for some time (see Schoutrop 2003 for an overview). Even the standard concept of the psychiatrist's couch evokes an image of a person telling their story to the doctor. Michele Crossley, in her book, *Introducing Narrative Psychology*, describes the place of narrative in helping those with chronic illnesses like HIV establish a more positive sense of self and identity (Crossley 2000b).

The healing power of narrative as a tool to counteract traumatic experiences related to conflict and deployment has been widely recognized by projects such as *Operation Homecoming*, a collection of eyewitness stories from soldiers and their families published in an eponymous book (Carroll, 2006). Funded by the National Endowment for the Arts, well-known writers were brought together with soldiers for this project to inspire them to chronicle their stories for both personal healing and sharing with others.

Stories are powerful constructs that can resonate in both those that tell them and those who hear them. Stories connect us because we share them as a method for making sense of the world and the way we live in it (Baumeister and Newman 1994). Among other purposes, stories can be used to convey a shared social heritage that transcends generation, location, and culture. Stories about social roles common to many societies reveal themes that can bring a focus to the core strengths that reside in each one of us. For the authors, writing one's story can provide a sense of control for how their story is presented – what details are kept, which are downplayed or eliminated, and ultimately how the story is internalized and remembered. Even listening to a story that resonates can be therapeutic because such a story can shift the way an event is perceived in retrospect for those who understand the message of the tale. In *Story Logic*, David Herman says, "narrative understanding is a process of building and updating mental models on the worlds" (Herman 2008: 22). Thus, a relevant story helps us readjust how we comprehend our experience in the world. Crossley notes: "A vision of 'the good' becomes available for people in any given culture by being given expression or articulation in some form or another. This articulation most often occurs through language and symbolic systems, such as custom and ritual, which reverberate with knowledge of connections and relationships across generations" (Crossley from C. Taylor 1989: 91). She continues, "We have a sense of who we are through a sense of where we stand in relationship to 'the good'" (Crossley 2000a: 533). By supporting this sense of our self in relation to what is best in a culture, narratives can set the stage for a

©2010 ICDVRAT; ISBN 978 07049 15022

healthier world view, which leads to the opportunity to achieve "integration, adaptation, peace and closure" (158).

Because our target audience comprises returning veterans, there is a risk of opening up memories that may be painful or traumatic. The intent is not to explore negative events, but to focus on the positive (Crossley's "good") by emphasizing the honorable stories and aspects of service. By organizing experiences into a story, whether by writing or by imagery, the experience "which was static, frozen, totalizing, and formerly unknown, becomes not only known, but something that can be revised, and therefore multiplied, changed and re-seen." (Sinor 2003: 414) Several researchers note that the capability of revising the story is a key aspect of recovery from traumatic events, giving a sense of control back to the narrator (Warnock 2000) (Johnson, 2000). As Anderson & MacCurdy, two prominent narrative experts state: "… writing that heals is often writing in which the writer names, describes, and takes control of experiences in which the powers of naming and controlling have been explicitly annihilated." (Anderson and MacCurdy, 2000: 85)

PTSD and other traumatic responses caused by the stressors of long deployments, constant vigilance and dangerous situations have many symptoms. One of these is a loss of self-esteem, or a sense of shame, among some soldiers. As early as 1992, Wong and Cook delineated the contribution that shame has to PTSD with their study of Vietnam veterans (Wong and Cook 1992). Countering this loss of self-esteem is one of the primary goals of the "Warriors' Journey" experience. By correlating honorable and respectable values of great warriors throughout history with the experiences service members have faced today, and emphasizing the warrior ideals, we hope to help revitalize the self-image of veterans affected by traumatic events.

While the act of writing has been shown to have healing benefits for the self, as described above, our story experience is not focused on writing per se, but on imagery, sounds, narration and interaction. Recent brain research indicates that traumatic memories reside in the non-language centers of the brain, e.g. the amygdala, which is part of the brain's mechanism to react to and store emotional events (Buchanan et al. 2001). It is also the brain area implicated in "appetitive" or positive conditioning via imagery (Paton et al 2005). The emotional part of the brain is a powerful part of our emotional makeup and memory formation. By using imagery as a key element of the interactive story experience, we hope to tap into the working mechanisms of our brain to form emotional memories, and thus increase the chances that the story will resonate with those who experience it.

3. CREATING THE EXPERIENCE

Our efforts to use narrative are unique in that we combine multiple storytelling techniques (visuals, sounds, narration) with artificial intelligence (AI) and embodied conversational agents (ECAs) within an online virtual world setting. Story experiences are not unknown in the Second Life virtual world. There are many excellent examples including Numbakulla (a solo questing experience in which all communication occurs through placed objects), the Gorean role-playing lands (all communication through real life individuals piloting the avatars, with the story emerging from their interactions), and the innovative narrative Gone Gitmo (which forces the avatar to take on the role of a recently captured prisoner of war being sent to the infamous Guantanamo Bay military prison). While these provide a wide range of satisfying and interesting storytelling venues in Second Life, none of these use embodied conversational agents to facilitate the story information and interaction (Carr and Pond 2007) (Weil and de la Peña 2008).

Agent use in the virtual online world of Second Life is a relatively new area of exploration, with a limited number of examples (originally used for functions such as modeling virtual outfits for sale, land sales, scouting for land, and parcel management in communities). More recently, ECAs have been implemented in SL for various purposes: as virtual guides in the Army's public SL space (Jan et al. 2009); as part of an experiment to determine the social spatial norms in a virtual world (Friedman, et al. 2007); and to showcase an intricate virtual model of the ancient Chinese war strategist, Sun Tzu (Fliesen 2009). We create our avatar-agent in SL in much the same way a Second Life resident creates his or her own avatar –with careful design considerations related to physical appearance, costuming, voice, and gestures. This agent is "logged into" SL via a server, and set to run according to the scripts that control its movements and responses (this will be covered in more detail in Section 4: Technology).

There has been tremendous progress in ECA research over the last decade. From simple chatbots to ECAs that can negotiate and have emotions, the ranks of these highly functional agents are growing. Interactivity is the hallmark of these agents, with typed or spoken word conversations the standard implementation (see for example Cassell et al. 2000) (Traum et al. 2003) (Swartout et al. 2010). We have expanded this agent work by bringing them into larger functionality in the virtual world domain and setting them in the guise of a storytelling activity.

©2010 ICDVRAT; ISBN 978 07049 15022

ECAs are not usually associated with storytelling, per se, with a few notable exceptions (Cassell 2001). Michael Mateas's Façade project, outside of Second Life, is a good example of a high-end approach to interactive storytelling with agents (Mateas and Stern 2004). Not only are the story's main characters agents themselves (Trip and Grace, a seemingly successful married couple), but there is also a hidden drama agent that monitors the interactive simulation and makes decisions about what the two protagonists do during the extent of the event. The story within Façade arises from the choices made by the participant in their engagement with the agents within the setting (the couple starts fighting and you are dragged into the conversation). The Façade story has a strong sense of psychological immediacy, elicited by using an uncomfortable situation to heighten the drama.

On the other end of the ECA spectrum are chatbots (Mauldin 1994). Chatbot agents are a form of autonomous virtual humans that process natural language in some way. They are often not embodied and have limited general intelligence. Several versions of these can be found on the Web, such as the Pandora bot (Pandorabot: Pandorabot chatbot hosting service, http://www.pandorabots.com/pandora). We felt it important to have an embodied agent that went beyond the capabilities of a chatbot by knowing a great deal of information about the domain and facts of the story. We also wanted the agent to be embodied so that the story would have a recognizable and memorable hero. Ulrilke Spierling (2005) proposed a framework that combines traditional storytelling and first person experience with an ECA which has informed our own implementation. He notes, "The overall goal is middle ground between predefined narrative and emergent conversations" (p 4). We have designed a story that starts with a linear walkthrough (an audio-visual experience with four distinct sections) and culminates in the conversational interaction with the narrator of that story. What the participant sees and hears in the narrated story primes them for their visit with the embodied agent.

As mentioned, we designed the stories in the Warriors' Journey experience to serve as positive reinforcement for veterans who need to regain a sense of self worth that might have been damaged in their war fighting activities. We aimed for contextually anchored stories, but not ones that paralleled too closely to the veterans' recent wartime experiences, as we did not want this to be confused with more standard Post Traumatic Exposure Therapy. Therefore, we decided to focus on historical entities that embodied the positive qualities we wanted to illustrate rather than overt messages about the current conflict. In this way we felt we could achieve deeper and more effective storytelling by selecting narratives that do not relate too closely to the context of the soldier's recent deployment experience, which might prove too intense to revisit.

Our goals in creating a series of stories about historical warriors through the ages are to: 1) find a cultural marker that can be an emblem of warrior values in a positive and reaffirming way, and 2) to identify a universal veteran issue that can be addressed/redressed cathartically through this marker. If something about these stories did not resonate with our soldiers, or if they could not identify with our far-off protagonists, then they would have little to gain from the stories.

3.1 The Story

For our first implementation we chose the Cheyenne Dog Warrior, a member of an elite Native American guard unit that put selfless duty among his highest callings.[3] A Dog Soldier would wear a long sash over his right shoulder, with a split end section trailing on the ground. If danger was eminent, the warrior would use a wooden stake to pin himself to the ground where he could defend his people. Once committed, only his fellow people could relieve him of this duty by unpinning him and/or yelling at him like a dog (Mails 1998). The key elements of the Dog Warrior story include: sticking to one's post (point of strength), and dealing with lost comrades (point of difficulty). In the Dog Warrior story, the cultural marker is the tradition of the Dog Rope, clearly emblematic of Selfless Sacrifice. When the participant finally meets the embodied conversational agent in the form of the Dog Warrior, he does so at the edge of the warrior's village where his fallen brethren are buried. Through witnessing and listening to the story of these acts of selfless sacrifice, our living hero (the veteran) must also deal with those who fought like him, and those who, unlike him, gave their lives. This is a clear issue for veterans: a parallel can be drawn between the Cheyenne, visiting the dog ropes (grave markers) of past warriors, to a soldier visiting a war memorial.

3.2 The Warriors' Journey Experience

The Warriors' Journey experience consists of two main parts. The first is the story path contained within an environment that contains images, sounds and narration. The second part is the interaction with the embodied agent as the Dog Warrior from the story, which happens after the initial tale has been experienced within the story space.

[3] Other stories in the planned series include the Samurai, Celtic and Spartan warriors.

©2010 ICDVRAT; ISBN 978 07049 15022

3.2.1 Environment Design. The environment that houses the story is a tower inspired by the designs of Mary Colter, a 1940s architect who was responsible for many designs in the American Southwest (Berke 2002). One tower she designed was made to look like an ancient ruin and stands at the rim of the Grand Canyon. We chose to emulate this design for two reasons. First, there is no specific culture assigned to the tower, though it has the appearance of great age. Second, we felt that an upward climbing journey would emphasize ascension and positivity as opposed to a straight or otherwise oriented path. Thus, the tower is an important metaphorical aspect of the Journey. The continual upwards path ascends into greater understanding and expanding knowledge. (See Figure 2.)

Many of the ideas enacted in the story space are also informed by expertise in museum design, where the visitor is on a path or journey to be traversed in order to gain some knowledge. We referenced the techniques of noted designer Philip Thiel. In his book**,** *People, Paths and Purposes*, he describes the environment experienced as "a path-contingent sequence of scenes" (Thiel 1997: 212). We used audible narration because we believed that voice would elicit more engagement from the participant than simply looking at images. Audible narration is an immersive "background" story delivery method. Unlike text, it does not require active participation, only passive engagement and presence.

3.2.2 Narrative. The narrative is brought to life not only by the voice of the narrator, but also by illustrations from the warrior's life (See Figure 1.). The spiral path of the tower keeps the participant travelling a proscribed path that focuses attention on the details of the story we want the user to know and understand. Upon entering the story space, the user becomes immersed in the story through the limited path, the visuals, sounds and narration. Because these elements are minimal and succinct, the setup allows for temporal interpolation where the story recipient must fill in the blanks on their own.

The four illustrated story panels are accompanied by non-diegetic sound elements such as music and a voice-over narration. These story panels, sounds and narration serve as background as well as fodder for the final conversation with the embodied agent who will be encountered in the next phase of the Warriors Journey.

3.2.3 The Touchstone room. At the top of the tower's spiral path, a threshold must be traversed to establish the final, personal connection to the Storyteller. Crossing over this threshold to what we call the Touchstone room, the participant finds himself face to face with the story's narrator (See Figure 4.). Crossing a threshold, in the thinking of Joseph Campbell, represents a change from one state of being to another, "venturing into an unknown and dangerous realm where the rules and limits are not known" (Campbell 1965). The physiognomy of this place beyond the threshold contains those denotative and connotative elements that bring it meaning, a unique character and quality, a "genius loci." In the Touchstone room, these "place qualifying agents" (as Thiel terms them) we include are the tipis, the travois, the various baskets and even the dog ropes from the fallen warriors on the ground. This is a deterministic space, one that Thiel calls a proactive medium – as it can actually facilitate a change of consciousness in the user-participant (p 340). Therefore, metaphorically, when one returns from this realm, they do so with a new wisdom that has been gained from experiencing the story, which is now integrated into one's own life.

3.2.4 Interaction with the agent. It is important that answers can be contextualized into the dog warrior story, especially those questions that relate to the soldier's own story. When the visitor encounters the Dog Soldier in the form of a 3D virtual agent in the Touchstone Room, he is standing at the edge of his village. This virtual agent finishes narrating his story in a face–to-face experience, with scripted body animations, music, and the same voice that is heard in the tower below. The agent character then essentially shifts the story from passive to a more active mode: he goes from telling the story to listening to questions the participant might pose, and answering them. The storytelling agent/warrior is in full costume, just as he was represented in the story panels. To support the answers being relevant and realistic, we have created a "Character bible" that sets the facts about the warrior that allows us to consistently and thoughtfully answer questions "as if" we were the virtual character. The character bible includes the warrior's name Hoetoo'otse, details about his family, when he was made a Dog Soldier, where he lived, who his people were, and other related facts.

At the story's conclusion, the participant is told he can ask the Dog Soldier questions about his background, history, and story. The Dog Soldier agent's conversational module, based on ICT's Virtual Human work (Leuski et al. 2008) is continually updated through this dialogue to enrich the knowledge base of the agent.

©2010 ICDVRAT; ISBN 978 07049 15022

3.2.5 Reward: Remember and Tell. After experiencing the warrior's narrative and interacting with the virtual agent, the participant earns the reward of being able to tell his own story in the Warriors' Journey Tower. With help from another intelligent agent, he can populate the story tower with his own images, sounds and text. He can also create a unique avatar (a 3D representation of himself) that can perform similar actions as the Dog Soldier character. In this way, the participant can tell his story and share it with others as part of a therapeutic enrichment exercise.

Figure 1. *An image from the warrior's life.*

Figure 2. *The Story Tower structure.*

4. TECHNICAL IMPLEMENTATION

The Dog Soldier is an Embodied Conversational Agent (ECA) as previously described. ECAs allow both verbal and non-verbal interactions in a virtual world (Cassell et al. 2000). In the current system, the Dog Warrior agent is designed to respond to questions asked by the participant and perform nonverbal gesturing. Visitors can interact with the Dog Warrior either in chat or over instant messages (IM). Chat and IM differ in two regards: chat is public but local: only those nearby can see and participate in the chat. IM has no distance limitation, but is private. The Dog Warrior can only be in one chat conversation (potentially multiparty) while he can participate in any number of private, dyadic IM conversations going on at the same time.

The agent's conversational domain is constrained to his background, life as a warrior and his values as a soldier. The motivation for this was to keep the exchange focused on the domain and not allow the conversation to fall out of the context of the activity. Provisions are made, however, to have responses to off-topic questions that might be asked. These answers can range from "I do not know" to "your language is different from my people's".

4.1 System Architecture

The user's questions are statistically analyzed and algorithmically matched to the best answer based on word order and word combination using a tool called the NPCEditor (Leuski et al. 2006). The user's question is compared against a list of potential paraphrased questions, which are associated with corresponding replies. If the question is unclear, the agent attempts clarification by responding with a leading question. The system can also withhold information until certain conditions are met, such as name exchanging, visiting a specific location, and achieving a cultural understanding or some other type of rapport. All communication is through local chat or IM in Second Life, so others can listen in or even join in the conversation. The system also has the option to express physical or verbal actions in response to a variety of environmental stimuli, such as avatar proximity, keywords, or patterns of movement. The Dog Soldier also uses some non-verbal gesturing as part of the interaction, such as a hand making a sweeping motion to draw a user's attention to the graves of his fellow warriors.

The main agent application is implemented in the programming language C# using LibOpenMetaverse (formerly libsecondlife), a freely available .NET based client library used for accessing 3D virtual worlds.

©2010 ICDVRAT; ISBN 978 07049 15022

This library implements the Second Life client-server protocol and allows for an ECA to connect to the Second Life virtual world in the same way a human user would connect by logging into the Second Life client. (See Figure 3.) LibOpenMetaverse exposes all avatar capabilities including speech, pathing, movement and gesturing to the various AI modules that control dialog, state and gesture, giving us maximum flexibility in crafting the ECA's actions and responses.

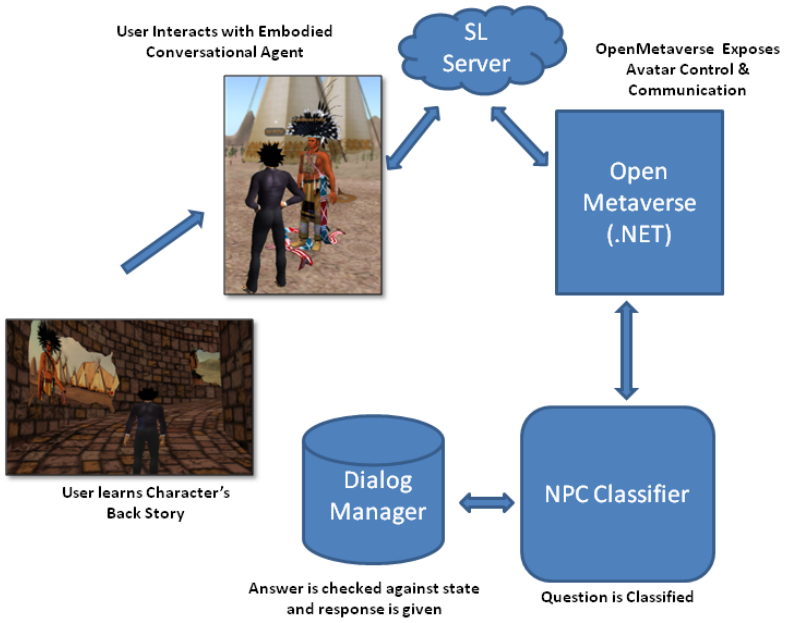


Figure 3. *Basic system architecture.*

4.2 Character Development and Dialog Model Authoring

There are several issues to consider when developing the content for the AI-based dialog. We must develop a list of potential questions that may be asked by the participant after being introduced to the agent. The general types of questions that must be addressed include greetings, answers to questions about the Dog Warrior's life, responses for off-topic or inappropriate questions, and closure/exit interactions. It is important that as many answers as possible be contextualized to the Dog Warrior story. This is an iterative process. After building the first dialog model, we performed several rounds of content revisions based on actual conversation logs generated from interactions between visitors and the Dog Soldier agent.

4.3 Example of Interaction

***kip Artful**: hello*
***Spellbinder Portal whispers**: Hello.*
***kip Artful**: who are you*
***Spellbinder Portal whispers**: I am a Dog Soldier.*
***kip Artful**: where are you from*
***Spellbinder Portal whispers**: I am from the Cheyenne territory, over the great hill.*
***kip Artful**: did you see battle?*
***Spellbinder Portal whispers**: I fought in many battles, first against the Kiowa, then later against the Pawnee*
***kip Artful:** where is your family?*
***Spellbinder Portal whispers**: I never took a wife or fathered children. My family was the Dog Soldiers. They were my brothers, and we took care of each other.*
***kip Artful**: is that a gun?*
***Spellbinder Portal whispers**: We Dog Soldiers favor bows and arrow, but we will use other weapons as well, such as the spear and the gun.*
***kip Artful**: why did you fight?*
***Spellbinder Portal whispers**: I fight to defend my people, and my way of life. That is the only reason I have ever known.*
***kip Artful**: how did you fight?*

©2010 ICDVRAT; ISBN 978 07049 15022

***Spellbinder Portal whispers**: I fought in many battles, first against the Kiowa, then later against the Pawnee*
***kip Artful**: where is your horse?*
***Spellbinder Portal whispers**: Many Dog Soldiers rode horses into battle, but I was charged with the dog rope. A horse will turn away, where a man can stand his ground.*
***kip Artful**: did you have fear?*
***Spellbinder Portal whispers**: A Dog Soldier must appear brave. Still, when I pinned myself to the ground I was afraid. More afraid than I had ever been before. I was fighting for my life with nowhere to run. Yet when the Kiowas saw me, they didn't see the fear in my eyes, only the rope pinning me to the spot and the sharpness of my arrows. Many of us fell that day, but in the end it was the Kiowas who fled. We protected our people.*
***kip Artful**: where is your family?*
***Spellbinder Portal whispers**: You know our people as the Cheyenne, but we call ourselves the Tsitsistas. Tsitsistas simply means "our people."*

Figure 4. *Example of conversational interaction in the Touchstone Room.*

When the participant has finished asking questions (i.e. when 30 seconds without a question have elapsed) a final message appears in the chat window that explains how to leave the Story Tower. Once outside, the visitor can choose to re-enter the tower and experience yet another Warriors Journey story, or ask to start building his own.

5. CURRENT STATE AND FUTURE WORK

The Cheyenne Dog Soldier was initially tested by a limited group of volunteer participants. Approximately 25% of those surveyed were active, retired or on reserve military duty. Preliminary results show that 93% of those surveyed indicated that they understood the background story of the Dog Warrior. 84% indicated that it would be meaningful to author their own story in the story tower and 85% of those surveyed indicated that they felt the activity could be a useful tool for veterans. Here is a quote from one recently returned Marine that participated in the testing phase;

> *" I believe that it may be therapeutic for a returning/returned veteran to be able to author his own story if he believes it to be. Troops coming back have struggles both big and small. I reintegrated fairly easily; many of my friends and subordinate Marines struggled to get back into a routine or feel comfortable doing anything and everything. It's hit or miss, different strokes for different folks kind of thing - but, I do believe any vehicle for allowing somebody to get some of the shit out of their head which may be troubling them certainly has value to veterans and those reconnecting. The story tower seemed to do some pretty cool and interesting stuff."*

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

We are planning more detailed studies in the coming year to determine how these stories actually affect returning veterans. We are also eager to test whether getting to author a personal story in the story tower space in the virtual world is seen as a positive, beneficial activity. We expect, as Jennifer Sinor states, that being able to relate and share one's stories about war will be "primarily an act of testimony, a public ritual of healing." (1997, 405)

6. CONCLUSIONS

In the book, *An Introduction to Narrative Psychology*, Dr Michelle Crossley argues that "The concept of self is inextricably linked to language, narratives, others, time and morality. […] The aim of narrative psychology is therefore to study the language, stories and narratives which constitute selves and the implications and permutations of those narratives for individuals and societies" (Crossley et al. 2000). It is our hope that this two-fold experience, looking at classic warriors' journeys and authoring one's own warrior's story, will help start wounded warriors on a path to healing through personal narrative expression.

Acknowledgements: We would like to thank David Traum and members of the Natural Language Group at USC's Institute for Creative Technologies for their work on the language understanding and storyteller AI. Jamie Antonisse created the stories for the Dog Warrior and the Samurai, and Sean Bouchard contributed extensively to the story and design ideas. The project or effort described here has been sponsored by the U.S. Army Research, Development, and Engineering Command (RDECOM). Statements and opinions expressed do not necessarily reflect the position or the policy of the United States Government.

7. REFERENCES

A Frank (1997), *The Wounded Storyteller: Body, Illness and Ethics*, University Of Chicago Press, Chicago.

C M Anderson, with K Holt and P McGady (2000), Suture, Stigma, and Pages that Heal, *Writing and Healing: Toward an Informed Practice*, (C M Anderson and M MacCurdy, Eds), National Council of Teachers of English, Urbana, pp. 55-82.

R Baumeister and L Newman (1994), How Stories Make Sense of Personal Experiences: Motives that Shape Autobiographical Narratives, *Personality and Social Psychology Bulletin*, 20, 6, p. 676.

A Berke (2002), *Mary Colter: Architect of the Southwest*, Princeton Architectural Press.

T W Buchanan, N L Denberg, D Tranel (2001) Verbal and Nonverbal Emotional Memory Following Unilateral Amygdala Damage, *Learning and Memory* 8,6. pp. 326-35.

J Campbell (1965), *The Hero with a Thousand Faces*, Pantheon Books.

J Cassell, J Sullivan, S Prevost and E F Churchill (2000), *[ECA] Embodied Conversational Agents*, MIT Press.

J Cassell (2001), Embodied Conversational Agents: Representation and Intelligence, *User Interfaces, AI Magazine*, Volume 22,4.

P Carr and G Pond (2007), *The Unofficial Tourist Guide to Second Life*, St. Martins' Griffin Press.

M Cavazza, F Charles and S Mead (2002), Interacting with virtual characters in interactive storytelling. *Proc of the First International Joint Conference on Autonomous Agents and Multiagent Systems*, Bologna.

M Crossley (2000a), Narrative Psychology, Trauma and the Study of Self/Identity, *Theory Psychology* 10 pp: 527-546.

M Crossley (2000b), *Introducing Narrative Psychology, self, trauma and the construction of meaning*, Open University Press.

D Fliesen (2009), *Sun Tzu Virtual Guide* retrieved from http://openvce.net/sun-tzu on June 15, 2010.

A Frank (1997), *The Wounded Storyteller: Body, Illness and Ethics*, University Of Chicago Press, Chicago.

D Freeman, A Stead, and M Slater (2007), Spatial Social Behavior in Second Life, In , Proceedings of the 7th International Conference on Intelligent Virtual Agents, Springer, Berlin. pp 253-263.

S Gandhe, D DeVault, A Roque, B Martinovski, R Artstein, A Leuski, J Gerten, D Traum (2008), From Domain Specification to Virtual Humans: An Integrated approach to authoring tactical questioning characters, *Proc 9th Annual Conference of the International Speech Communication Association, Interspeech 2008*, Brisbane.

D J Herman (2008), *Story Logic: Problems and Possibilities of Narrative: Frontiers of Narrative*, University of Nebraska Press.

T R Johnson (2000), Writing as healing and the Rhetorical Tradition. *Writing and Healing: Toward an Informed Practice,* (C M Anderson and M MacCurdy, Eds), National Council of Teachers of English, Urbana, pp. 85-114.

A Leuski and D Traum (2008), A Statistical Approach for Text Processing in Virtual Humans, *Proc of the 26th Army Science Conference*, Orlando.

A Leuski, R Patel, D Traum, and B Kennedy (2006), Building Effective Question Answering Characters *in Proc of SIGdial Workshop*, Sydney.

M M MacCurdy (2000), From Trauma to Writing: A Theoretical Model for Practical Use, *Writing and Healing: Toward an Informed Practice* (C M Anderson and M MacCurdy, Eds), National Council of Teachers of English, Urbana, pp. 158-200.

W E Mackay (1995), Ethics, Lies and Videotape, *Proc. CHI 1995*, Denver, 138-145.

T E Mails (1998), *Dog Soldier Societies of the Plains*, Marlowe and Company, New York.

M Mateas and A Stern (2002), A Behavior Language for Storybased Believable Agents, *IEEE Intelligent Systems, special issue on AI and Interactive Entertainment.*

M Mateas and A Stern (2004), Natural Language Understanding in Façade: Surface-text Processing, *Proc. 2nd Technologies for Interactive Digital Storytelling and Entertainment (TIDSE '04)*, Darmstadt.

M Mauldin (1994), ChatterBots, TinyMuds, and the Turing Test: Entering the Loebner Prize Competition", *Proceedings of the Eleventh National Conference on Artificial Intelligence*

J J Paton, M A Belova, S E Morrison and C D Salzman (2005), The primate amygdala represents the positive and negative value of visual stimuli during learning, *Nature* 439, pp. 865-870.

J Pustejovsky (1995), *The Generative Lexicon*, MIT Press.

J Rickel, S Marsella, J Gratch, R Hill, D Traum and W Swartout (2002), "Toward a New Generation of Virtual Humans for Interactive Experiences, *IEEE Inteligent Systems*, July/August, p. 32-38.

M Riedl, R M Young (2004), An intent-driven planner for multi-agent story generation, *Proc. 3rd International Conference on Autonomous Agents and Multi Agent Systems*, New York.

M Schoutrop, A Lange, J Bross, and W Everaerd (1997), Overcoming Traumatic Events by Means of Writing Assignments. In A Vingerhoets, F van Bussel, J Boellhouwer (Eds), *The (Non)expression of Emotions in Health and Disease*. Tilburg University Press, Netherlands, pp 279-289.

J Sinor (2003), Inscribing Ordinary Trauma in the Diary of a Military Child. Biography, 26,3, pp 405-427.

U Spierling (2005), Interactive Digital Storytelling: Towards a Hybrid Conceptual Appropach, *Proc. 2005 Digital Games Research Association (DIGRA) Conference: Changing Views- Worlds in Play.*

W Swartout, D Traum, R Artstein, D Noren, P Debevec, et al. (2010), Ada and Grace: Toward Realistic and Engaging Virtual Museum Guides. To appear in *Proc. Of the 2010 International Virtual Agents Conference.*

P Thiel (1997), People, *Paths and Purposes: Notations for a Participatory Envirotecture*, University of Washington Press.

D R Traum, J Rickel, J Grach and S Marsella (2003), Negotiation over tasks in hybrid human-agent teams for simulation-based training, *Proc. 2nd International Conference on Autonomous Agents and Multi Agent Systems*, Sydney, pp. 441-448.

M Walker (1996), Inferring Acceptance and Rejection in Dialogue by Default Rules of Inference, *Journal of Language and Speech*, 39,2.

T Warnock (2000), Language and Literature as 'Equipment for Living': Revision as a Life Skill. *Writing and Healing: Toward an Informed Practice,* (C M Anderson and M MacCurdy, Eds), National Council of Teachers of English, Urbana, pp. 34-57.

P Weil and N de la Peña (2008), Avatar Mediated Cinema, *Proc of the 2008 International Conference on Advances in Computer Entertainment Technology*, 352, ACM Press.

M R Wong, D Cook (2006), Shame and its Contributions to PTSD, *Journal of Traumatic Stress*, 5,4, pp. 557-562.

R M Young, M Riedl, M Branly, R J Martin and CJ Saretto (2004), An architecture for integrating plan-based behavior generation with interactive game environments, *Journal of Game Development*, 1,1, pp. 51-70.

©2010 ICDVRAT; ISBN 978 07049 15022

Extending body and imagination: moving to move

D Wilde[1], R J N Helmer[2], M Miles[3]

[1]Ishikawa Komuro Laboratory, University Of Tokyo,
Hongo 7-3-1, Bunkyo-ku, Tokyo, JAPAN

[1,2]Division of Materials Sciences and Engineering, CSIRO,
Henry Street and Colac Road, Belmont, Geelong, VIC, AUSTRALIA

[1,3]Faculty of Art & Design, Monash University,
900 Dandenong Rd, Caulfield East, Melbourne, VIC, AUSTRALIA

[1]*d@daniellewilde.com,* [2]*Richard.Helmer@csiro.au,* [5]*Melissa.Miles@artdes.monash.edu.au*

[1]*www.daniellewilde.com,* [1]*www.k2.t.u-tokyo.ac.jp/members/index-e.html*
[2]*www.csiro.au/science/ps3xg.html,* [3]*www.artdes.monash.edu.au/theory/staff/mmiles.html*

ABSTRACT

We present a range of body-worn devices that have evolved from a common design intent: 'to move the body through real and virtual extension'. These devices encourage people to move in extra-normal ways, and thereby view and experience their bodies from perhaps hitherto unknown perspectives. They provide a rich playground for self-expression, as well as learning opportunities that we believe might be relevant for people with physical challenges and unconventional or altered abilities. Our desire in presenting this work to the ArtAbilitation community is to open up a dialogue and examine opportunities for engagement.

1. INTRODUCTION

Swing That Thing: moving to move is a practice-based doctoral research investigation into the potential of technologically supported gestural, physical and sensorial extension to poeticise experience by encouraging physical engagement (Wilde 2007-2011). The praxis outcomes discussed here encourage people to explore and move in playful ways. They open up a free-form expressive space that affords insight into how our bodies can move and what this feels like; individual body-centric learning preferences; and the idiosyncratic nature of personal, corporeal expressiveness. The different approaches taken are outlined and discussed in relation to ArtAbilitation. Our expertise is not in disability research, so our suppositions in this area risk being naïve. Nonetheless we see many applications for this work in the area of disability. Embodied communication and the notion of a poetics of embodied engagement are integral drivers of this research. We believe they are also highly pertinent for people with disabilities, including physical and other challenges related to self-expression. We will discuss the praxis outcomes in relation to these ideas, touching upon possible therapeutic applications. We hope to find opportunities to explore the potential benefits of extending this research in deep and seriously playful ways into an 'abilitation' context.

2. MOTIVATION & METHODOLOGY

2.1 Art • Science • Everyday Life…

All products are cultural, yet art has the closest association with culture. Bringing art into the development of products, no matter what they're used for, can bring those products closer to people. This research foregrounds body and imagination in a quest to consider what a poetics of embodied engagement might be. It is motivated by a desire to get people moving, because moving feels good. Conception and the development of the praxis has been guided by art and design ideation techniques and intuitive processes. The desire has been to encourage people to explore and extend the range of movement they have available to them, by providing unusual and engaging opportunities for them to move in extended, self-directed ways. The results are idiosyncratic, open systems for expressive engagement that encourage different qualities of attention. There is no right or wrong way to proceed, no required or desired outcome. Participants are free to create their own dynamically evolving frameworks for use. This allows for the generation of activities pitched at an

©2010 ICDVRAT; ISBN 978 07049 15022

appropriate, or desired level. It also allows the difficulty to be increased or decreased at the participant's will. Outcomes are uncontrolled, and benchmarks are set by participants, so the devices can be used by novices, experts and elite movers, as well as by people with different challenges and unconventional abilities. Specific characteristics and potential applications of the different systems are described in Section 3.

2.1.1 Evaluation. Evaluation has focused on creating a common language and shared experience as a prelude to more formal qualification. Observation, open interview and subjective reporting of participant experience have been integral. Researcher participation has also played an important role. As participants attempt to translate pre-reflective (non-observational) subjective experiences into language, these reports must also be compared. Having personal non-observational experience of using the interfaces seems to enhance the researchers' ability to ask relevant questions, to gain clarification of what participants might mean. The common experiences act as a support for the development of an appropriate articulation of something that is extra-discursive.

2.1.2 Technology and Design. The research is arguably neither art nor science, rather it sits somewhere in between and has applications in both. In the Meta Perception Group at the Ishikawa Komuro Laboratory we develop interactive systems for applications in new media art and altered ability contexts[1], as well as examining the ethics of advanced technology systems. The Advancing Human Performance Theme at CSIRO undertakes empirically-driven research into technical- and intelligent-textile devices for sport, entertainment and health. They develop increasingly rigorous evaluation techniques with which to characterize the devices' performance, looking at accuracy, precision, robustness and repeatability, as well as the tangible experience of using sensory augmentation technology. The desire is to ascertain if a device yields a desired outcome, consistent with a hypothesis. The *Swing That Thing…* research contrasts with, complements and is informed by the different approaches of these contexts, leveraging many of the outcomes to link the practical, tangible aspects of body-worn technologies to the highly subjective feel of their experiential use.

2.2 Methodology

Swing That Thing… is a systematic examination of technological extension of the body (see fig.1). On a practical level, different forms of extension have been conceptualised, crude working prototypes made, and the ideas examined experientially. Consideration has been given to the impact of choices throughout the development cycle, including the aesthetics of the interface, as well as of the interaction. Prototypes are developed sufficiently to understand the impact and affordances of each approach, and to identify potential applications. Early insights are used to explore how and why different approaches might impact experience, and what this means for movement. Field-testing is undertaken with as broad a variety of individuals as possible, and includes prototype development if necessary. Extreme case scenarios are of particular interest (Moggridge 2006). People with a range of skills, as well as individuals with varying interests in personal and physical expression are encouraged and supported to test the devices. As potential applications are identified, prototypes may then be developed into more robust systems (for an example, see Wilde et al, 2010).

2.3 Reporting / Results

It is important to note that we are reporting outcomes that suggest a range of applications, without having yet fully tested our hypotheses. Our methodology supports emergent outcomes that are not discipline specific. We have an open way of working that affords the emergence of surprising outcomes, including unexpected opportunities to undertake empirical research. Under these circumstances, evaluation is based on fragmentary information.

Nonetheless, participants have consistently been engaged with the devices for extended periods of time, have expressed a desire to 'have one for themselves', or to share it with friends or children, even though the devices are not fully developed. Participants have also repeatedly suggested a broad range of applications, particularly in the area of disability[2]. We therefore feel that reporting at this stage is appropriate. It is helpful to understand and shape how the work might move forward in an ArtAbilitation context, as well as to engage with this community to consider the benefits of working in openly structured ways, making open systems for engagement.

[1] See especially *http://www.k2.t.u-tokyo.ac.jp/members/alvaro/works/index.html*
[2] Most commonly where they have personal experience with people with the disability in question.

©2010 ICDVRAT; ISBN 978 07049 15022

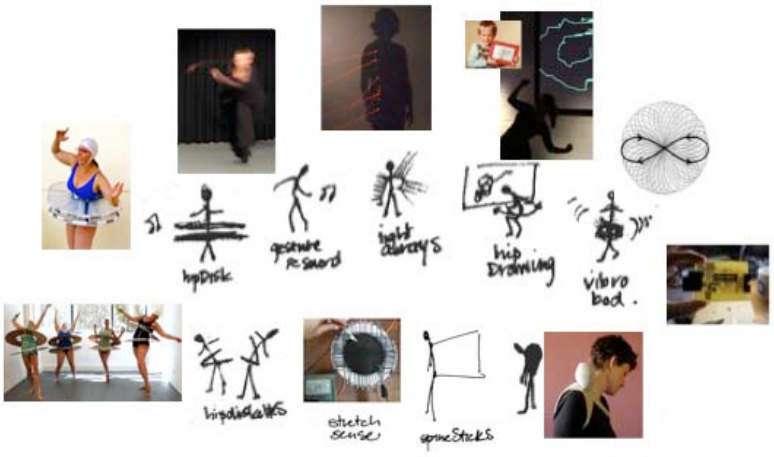


Figure 1. *Swing That Thing : moving to move [Wilde, 2007-2011].*

3. THE SUITE OF *SWING THAT THING…* DEVICES

This section provides an overview of the praxis outcomes that have emerged from the *Swing That thing…* investigation (fig.1). The suite of devices cover a range of augmenting approaches: extending the body with light; simple and complex sound; graphic output; vibrotactile feedback; and literal, physical, tangible extension of the core of the body, horizontally. Soft prosthetic extensions have also been developed, and participants have been invited to create their own exploratory devices. Each of the projects provides a different kind of feedback, and has its own affordances. It is beyond the scope of this paper to address in detail many of the technical choices. We provide sufficient information to support our discussion of how this work might be relevant to ArtAbilitation. More detailed information and publications are available at (Wilde, 2007-2011).

3.1 Extending through technology

The works discussed are presented in the chronological order of their conception. Development was staggered at the outset, yet each project continues to inform and be informed by the other projects, as they build towards a coherent thesis.

3.1.1 hipDisk (Fig.2). The *hipDisk* extends the body horizontally to exploit changing relationships between hip and torso to actuate simple tones. The interface consists of twelve soft binary switches spread evenly around the periphery of the two disks: one worn above, and one below the waist. As the wearer tilts their hip and torso in opposition, making the disks touch, different notes can be triggered. A number of tonal arrangements and scales have been tested: a chromatic scale, a major scale and a minor scale. Different participants have different preferences, so currently all three options are made available. The *hipDisk* constrains, and requires a particular kind of extension. It brings to light idiosyncrasies in posture and flexibility. It also, surprisingly, provides information about individual body-centric learning preferences, as people instinctively look for the most comfortable way to learn how the device behaves – through visual supports; physically: proprioceptively and kinaesthetically, as well as with tactile support from others; through sound; or observation. Some participants even use spatial orientation even though the interface is

Figure 2. *hipDisk and the hipdiskettes [Wilde, 2007]*

©2010 ICDVRAT; ISBN 978 07049 15022

self-contained and centred on the body, so no matter which direction the wearer faces the behaviour of the device is consistent. (Wilde, 2008)

Because of the visual resemblance, the *hipDisk* is repeatedly compared to the hula hoop, though the physical actions required to play the devices are very different. Visually, they both form a ring around the body's core. Physically, moving the hips in extended and powerfully intentional ways is not a common activity, outside of an intimate context. It can be highly pleasurable. In the case of *hipDisk*, it also looks very strange. We do not normally view the body extended horizontally. We also do not normally undertake

activities that have a disproportionate relationship between effort and outcome. The *hipDisk* can require an inordinate amount of effort to play certain notes (this differs for each person, and is related to posture and flexibility), yet the outcome is a reedy, almost tinny, unrefined tone. There is nothing sophisticated or graceful about the *hipDisk* in any traditional sense, yet participants love wearing it and playing with it, just as most people love to play with a hula hoop, given the chance.[3]

The hipdiskettes (Fig. 2) iterate the different aspects of *hipDisk* through time and space to afford a deeper examination of the interconnection between choreography and composition, as well as more complex sonic output. They were formed to perform a rendition of the Bossa Nova standard, *The Girl From Ipanema*. To date they haven't succeeded. It has become apparent through presenting the failure of their attempts that the humanity of their struggle is incredibly endearing and encourages people to want to play the device themselves. It seems that, as it's seemingly impossible to succeed with the *hipDisk*, there is no threshold of success or failure, so use of the device is democratised. The interface is simply fun, and provides a challenge that is engaging, entertaining and novel, and it can be use in as complex a way as the participant desires.

When participants use the *hipDisk*, they work together or alone, they mimic other participants or do opposing experiments. They rarely remove the device in under half an hour, and when they do they seem highly energized and to date always desire to describe their experience playing it and discuss how their use compares to that of other people. *hipDisk* provides a novel opportunity for self-expression, exploration and knowledge generation through playfulness and social engagement. The therapeutic value of this seems clear for able-bodied participants – the device is fun and it connects people to their bodies and provides self-knowledge. We believe there would be similar benefits for people who are less physically-abled. While *hipDisk* may not address particular physical pathologies, it may be useful for other kinds of pathologies where self-confidence and embodied engagement are an issue. It is also attached to the body in a very firm yet comfortable way, clasping the torso above and below the waist. This may be pleasurable for people who respond positively, and are calmed by pressure.

Figure 3. *gesture≈sound experiments [Bencina et al., 2007]*

3.1.2 gesture≈sound experiments (Fig. 3). The *gesture≈sound experiments* extend the body with sound to mesh gestural/physical and sonic composition in such a way that sound production seems to be an inherent and unavoidable consequence of moving the body. The desire is to encourage people to explore through movement and sound, interdependently; and also to understand the nature of engagement when the physical interface is relatively discrete. The tested interface consists of Nintendo Wiimotes[4] bandaged to different parts of the body, sending sensor data to a computer running *Max*[5] to play sound patches developed in *Audiomulch*[6]. The sensors have been attached to forearms, shoulders, hips, upper and lower legs, spine and sternum. The different sound patches have been designed to encourage and support different kinds of movement exploration with each of the targeted body parts. (Bencina et al, 2008).

[3] Based on personal experience, as well as anecdotal evidence provided by hoopers in Australia, North America and Japan.
[4] Trademarks registered. Further info is available at *http://www.nintendo.co.uk/NOE/en_GB/wii_54.html*
[5] A registered trademark of Cycling74. Further information is available at: *http://cycling74.com/products/*
[6] An interactive music program created by Ross Bencina. Further info is available at *http://www.audiomulch.com/*

©2010 ICDVRAT; ISBN 978 07049 15022

Gesture≈sound is free and unconstrained, in comparison to *hipDisk*. Any movement (of the Wiimote) can be tracked, within the constraints of the different patches, and the sound is algorithmically generated, so relationships between gesture and sound can be far more complex than the binary offerings of the *hipDisk.* The unconstrained nature of *gesture≈sound* opens up a free-form expressive space that can be used to encourage exploratory movement with targeted parts of the body. If language is, indeed, generated out of movement (Gallagher, 2005), increasing a person's capacity for movement expression may support greater ease with verbal expression, as well as other forms of communication. It has been suggested that *gesture≈sound* would be useful for people with spectrum disorders, in particular Autism, where the children in question have inordinate amounts of energy and have a tendency to obsess and make patterns. In its current form the sensors are worn, rather than integrated into garments, so this may or may not be an issue – depending on whether the participant gains pleasure and comfort from physical pressure, or is hyper-sensitive to touch (or somewhere in between). Informal discussions with parents of children with Autism suggest that developing the interface for their use would be welcome and worth pursuing[7].

3.1.3 The Light Arrays (Fig. 4). The *Light Arrays* extrude the body with light to magnify articulations, gestures and postures. They highlight how a person's movement impacts space physically and how the different parts of their bodies interact with each other and others in shared space. The system uses either lasers or LED arrays, which, to date, have been attached to the limbs, the spine and the core of the body. By incorporating lights into garments and modular fabric supports, the *Light Arrays* prompt wearers to interact and engage, through the lights, with body position and movement as well with their dynamic position in space. Wearers report being inspired to move in new ways and to discover and explore their bodies through movement, in ways that differed from their usual methods, approaches and habits (Wilde, 2007). Though the wearer cannot see the lights in their entirety, this has been reported to be inspiring, rather than frustrating. The *Light Arrays* are currently undergoing extended development. A discussion of the aims and objectives, as well as its relevance to the ArtAbilitation community is provided at (Wilde et al, 2010).

Figure 4. *Light Arrays [Wilde, 2008].*

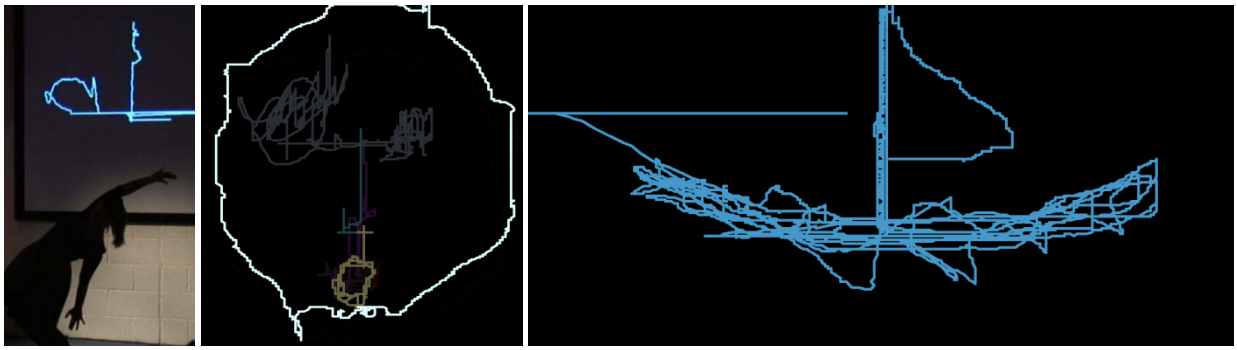


Figure 5. *hipDrawing and some hipDrawn images (2009) [Wilde, 2007-2011]*

3.1.4 hipDrawing (Fig. 5). The *hipDrawing* interface turns the wearer into a human, hip-controlled Etch-A-Sketch[8] by transforming hip-movement data into 2D graphics, which are projected onto a wall or screen. The interface uses custom textile sensing technology (Helmer et al, 2008) to measure change in relative tilt between the hip and torso. The data is sent wirelessly to a computer running Processing[9]. A version will also be made that sends the graphic output to a smart phone or PDA, eliminating the need for a projector, laptop

[7] The open nature of all of the systems has been remarked upon in informal conversations with parents of children with Autism. In each case they are eager for their child to have access. They suggest that the openness presents an opportunity for their child to engage in an exploratory manner, in a system that operates outside of language, and has room for their idiosyncrasies.

[8] A registered trademark of Ohio Art: *http://www.etch-a-sketch.com*

[9] An open source programming language and environment. Further information is available at: http://processing.org/

©2010 ICDVRAT; ISBN 978 07049 15022

computer, and architecture to support the projection. The *hipDrawing* garment also incorporates an accelerometer, so that shaking the body can be used to erase the drawing (just as shaking the Etch-A-Sketch screen erases the Etch-A-Sketch drawing). It is currently made for one participant, but a multi-user version is planned to examine social navigation and engagement. In the multi-user version, participants draw on a shared screen. If one person shakes their body (or is shaken), the entire drawing is erased and their 'line' goes to the bottom of the hierarchical structure, allowing the other participants to draw over the top of their new drawings.

hipDrawing has a very clumsy mapping: the relatively unconstrained three dimensional movement of the body at the waist, is mapped onto an *xy* axis. As a result, its use is sometimes anti-intuitive – moving the body can result in unexpected graphic output. To draw something specific requires an ongoing shift in attention between the actions and gestures of the body, and the resulting graphic output on the screen. This causes a quality of attention that is inhabitual, an intensity of focus that people would not normally turn to the body in movement. This intense scrutiny of hip gesture opens up knew ways of seeing, thinking, and generating knowledge about this part of the body. More intensely than any of the other devices in the *Swing That Thing…* suite of works, *hipDrawing* prompts a process of creating and reflecting on new modes and patterns of bodily experience, as facilitated by the interaction between body movement and the effects of the technology. The clumsiness of the mapping also serves to democratize the technology in a similar way to the clumsy, gracelessness of the *hipDisk*. It thereby results in a system that is highly accessible to people with varying abilities, as there is no 'right' way to succeed. Tasks can be designed for personal idiosyncrasies and desired challenge levels, and outcomes provide access to the inherent aesthetics of movements of all kinds. This may provide desirable experiences for people with a range of physical and communicative challenges, for self-knowledge, as well as for creative expression and playful physical engagement. See Gallagher (2005: 144-146) for an extended discussion of the interrelation of body schema and physical activity, and the benefits of engaging in different kinds of movement that affect motility and postural schemas, as well as the role of vision in proprioception.

3.2 Soft Prosthetic Extension

The OWL project (Fig. 6, 7) is also part of the *Swing That Thing…* suite of works, but it operates quite differently than the works described above. Rather than providing an open system for physically engaged creative expression that can assist in self knowledge and learning in, through and about the body, *the OWL project* engages participants in co-creation and collaborative imagining of that which does not yet exist. There are two parts to the OWL project: interviews and workshops.

Figure 6. *OWL devices [Wilde and Andersen, 2009].*

In the interviews, a series of soft prosthetics that do not contain technology are used to bring the wearer's attention to the body in inhabitual ways. The devices are open and speculative, designed without a pre-defined function and tested as design 'probes' to ascertain their functionality. As the interview progresses, each new device is incrementally stranger – the first two give and receive pressure, the next two destabilize by shifting the body off axis, and the third two are like mutations that extend out from the body in subtle, but unusual ways. Interviewees are asked simple questions like: How does it feel? What is it? What does it do? And if it gave you magical powers, what kind of powers would they be? The aim is to create an emergent, imaginative space in which people might be able to conceptualise technologies that don't yet exist. The desire is to plumb people's willingness to imagine through the body in movement; discover what might happen if we let people use their embodied experience and imagination to assist in the creation of unknown technologies; and to bring the wearers' attention to their embodied-ness to see if this brings them present to their inner state and encourages magical thinking. To date, interviews have been conducted in Europe (7), Australia (8), North America (6) and Japan (4 at the time of writing). The interviews are formalised, yet open. The objects are evocative, and the interview format is designed to slow down the moment of perception, 'making strange' that moment of considering an object as a worn presence within each personal space.

©2010 ICDVRAT; ISBN 978 07049 15022

The workshops are a little different. Rather than beginning with devices, participants are asked to choose a desire (Reiss, 2000), to decide where in their body it might live, then to build an exploratory object from recycled materials that somehow will embody their dreams, in relation to this desire, and give them magical powers. The workshops (3 so far) have taken place in Tokyo. Further workshops are planned for later this year, in Yamaguchi, Japan, and Sydney, Australia. The desire is to engage with as many people, from as many different cultural and socio-economic backgrounds as possible, as well as people with a range of relationships to movement and communication.

3.2.1 Creative Thinking Across Cultures and Communities. The geographical, cultural and socio-economic reach of the OWL project is giving us the opportunity to explore cultural differences and similarities expressed as creative thinking. Many of the outcomes are surprising, for example in one instance two people from radically different cultures, and political and socio-economic backgrounds used identical words to describe what one of the devices does. They were the only people to describe the device in this way. In another example, a participant who was interviewed in July 2009, reported in June 2010 that he has had lasting changes as a result of the things that were brought to mind during the interview process. His relationship to reading shifted, and he found himself examining why he did many things the way he did, and subsequently transformed many aspects of his life. He claims to be much happier as a direct result of the insights he gained during the interview. With regard to device #6, the quality of response has differed wildly, yet the valence has been the same. While it's difficult to draw clear conclusions from these outcomes, without exception, the experience of *the OWL project* has been reported as being unusual and bringing the attention to the body in new, different and deeply thoughtful ways. (Wilde and Andersen, 2009) We would like to see if this process might contribute in positive ways to how disabled people view and imagine through their bodies, as well as the kind of agency they imagine they might have with regard to the conceptualization and development of technologies that are relevant to them and are yet to be imagined.

Figure 7. *OWL devices and workshop inventions [Wilde and Andersen, 2009].*

4. MEASURING THE MOVING BODY

Measuring the body in movement is a major challenge for physically engaging interactive systems. *hipDrawing* and the *Extended Light Arrays* (Wilde et al, 2010) both make use of a custom textile sensor that has been developed at the CSIRO to measure elbow and wrist flexion, allowing for the relatively unconstrained movement and degrees of freedom in these parts of the body (Helmer et al, 2008). The sensor has been tested and compares favorably to the Vicon motion tracking system[10] – considered an industry "gold standard" for motion tracking. The advantage of using body-based sensors as opposed to a camera vision system such as Vicon is that body-based sensing is not restricted to the point of view of a camera (or cameras), the data can be followed in real time and, most importantly, testing can take place in any environment, including outdoors, as no installation of hardware or support systems are required. The CSIRO textile sensor connects to a body-worn microcontroller that sends data wirelessly to a laptop which has been set up to receive serial input via usb. In the *Swing That Thing…* investigation, the sensor has been adapted to measure flexion at the waist.

3.2.1 Mixing Music, Movement and Learning. The CSIRO textile sensor has been tested not just for accuracy of positioning data, but also for efficacy when using music to assist in learning. Researchers have worked with elite athletes at the Australian Institute of Sport[11], improving netball players' goal shooting skills by calibrating drum beats to wrist and elbow flexion. They have then examined how this information might be used to assist learning for novices, working with high school basketball players. They have also examined how adolescents learn, and teach each other about learning by embedding the sensors into a Wearable Instrument Shirt. The shirt allows elbow flexion to trigger controls on a virtual air guitar. In each case results have been notable. The netball and basketball players increased their skill levels significantly. The air guitar players were engaged, not just in the game, but also in sharing knowledge about how to play

[10] Vicon Motion Systems are a registered trademark of Vicon: *http://www.vicon.com/*
[11] The AIS, or Australian Insitute of Sport: *http://www.ausport.gov.au/ais*

©2010 ICDVRAT; ISBN 978 07049 15022

the game. The device has since been used as part of secondary education music classes to teach musical form and structure.[12]

The *Swing That Thing…* research extends this work to allow a participant to develop self-knowledge through creative expression. The intent is to examine how open systems and a variety of modalities might help people with different skills, interests and/or physical challenges, explore aesthetic possibilities through movement. The approach encourages creative engagement and allows for personal idiosyncracies. The systems' embodiments and constraints mean that less abled participants can explore these systems alongside more able participants with equally rewarding experiences.

5. REFLECTION

5.1 Foregrounding Physicality

The body is central to this enquiry, in particular the torso. We have a much lower resolution of control in the centre of our body than in our digits and limbs. Core body interaction is experienced in a very different way than more traditional forms of interaction achieved through mouse, joystick or other peripheral. It is often experienced as clumsy in comparison, which brings our attention to the body in unusual or unexpected ways. The focus of a person trying to control a clumsy body-worn interface shifts between actions and the results of actions, so the interactions between body movement, the effects of technology and the impact of each of the different types of extension become apparent.

Body-worn devices are very different to environment-based systems as they are normally tightly coupled with the body – they cannot usually be repositioned, picked up or put down. They thus support a very different kind of engagement than systems that are not body-worn, and provide opportunities for different kinds of physical experiences and knowing. Yet they provide a number of challenges for a less able-bodied participant because of this tight coupling. Putting a garment on may be challenging for some people, and different kinds of movement and form factors, if not allowed for in the design of a garment, may compromise sensor precision. For this reason it is essential to include otherly-abled participants in the development processes of body-worn technologies. Doing so will allow us to understand how to develop for the broad range of bodies in the community, rather than restricting use of the devices, and research responses to body-typical users.

The garments and devices described in this article are architecture independent, except *hipDrawing* in its current form. This also brings focus to the body – on the actions being undertaken, as well as on the results of those actions. It supports the aforementioned process of creating and reflecting on new modes and patterns of bodily experience, and allows for the research to be undertaken in almost any environment – wherever the participant feels most comfortable. We believe this is important when trying to gain data about how things feel through the body, as people's comfort levels and behaviours may shift in different environments. This may be particularly beneficial when working with people with physical and communicative challenges.

6. CONCLUSION

The praxis outcomes described here encourage people to explore and move in playful ways. They open up a free-form expressive space that affords insight into how our bodies can move and what this feels like; individual body-centric learning preferences; and the idiosyncratic nature of personal, corporeal expressiveness. They engage the mind, emotions and feelings with the body, in all its dynamic capacity that may have been hitherto ignored.

The open-ness of the systems, coupled with the, at times, clumsy nature of the interaction they afford, brings people to new ways of seeing and experiencing the body. There is no "right" way of performing tasks with these systems, there is simply an open environment in which to explore, and in which to find each individual's preferred approach. This is supportive of different levels of ability and prowess. It also supports the design of activities to achieve particular outcomes that acknowledge and support the individual's strengths and preferences. For all of these reasons, as well as the playfully engaging nature of the devices, we believe them to be ideally suited to disabled or physically and communicatively challenged individuals.

By engaging with the ArtAbilitation community, we hope to discover opportunities to explore these ideas, and to extend the research in deep and seriously playful ways with people with disabilities.

[12] such as blues chord progressions with one, four and five chords

©2010 ICDVRAT; ISBN 978 07049 15022

7. REFERENCES

R Bencina, D Wilde and S Langley (2008), Gesture≈ Sound Experiments: Process and Mappings *Proc. Intl. Conf. on New Interfaces for Musical Expression (NIME 08)*. Genova. pp. 197-202

S Gallagher, (2005) *How the Body Shapes the Mind.* Oxford University Press, USA.

R J N Helmer, M A Mestrovic, D Farrow, S Lucas and W Spratford (2008), Smart Textiles: Position and Motion Sensing for Sport, Entertainment and Rehabilitation. *Advances in Science & Technology* 60 (Smart Textiles), pp. 144-153.

B Moggridge (2006), *Designing Interactions*. MIT Press, Cambridge.

S Reiss, (2000) *Who am I: The 16 basic desires that motivate our actions and define our personalities*. Tarcher/Putnam, New York.

D Wilde (2007-2011), *Swing That Thing: moving to move.* Available from http://www.daniellewilde.com/dw/SwingThatThing.html

——— (2008), hipDisk: using sound to encourage physical extension, exploring humour in interface design. *International Journal of Performing Arts and Digital Media (IJPADM)* 4, 1, pp. 7-26.

——— (2007) *Light Arrays.* Available from http://www.daniellewilde.com/dw/lightarrays.html

D Wilde, K Anderson (2009), Doing things backwards: the OWL project. *Proc Australasian Computer Human Interaction Conference (OZCHI09).* Melbourne. pp. 357-360.

D Wilde, A Cassinelli, A Zerroug, R J N Helmer and M Ishikawa, (2010). Light Arrays: a system for extended engagement. *Proc. ICDVRAT with ArtAbilitation* Viña del Mar/Valparaíso, Chile

©2010 ICDVRAT; ISBN 978 07049 15022

Games for rehabilitation: the voice of the players

S M Flynn[1,2], B S Lange[1,2]

[1]Blue Marble Rehabilitation, Inc
Santa Rosa Ave, Altadena, CA, USA

[2]Institute for Creative Technologies, University of Southern California,
Waterfront Dr, Playa Del Rey, CA, USA

sherylflynn@bluemarblegameco.com, lange@usc.ict.edu

www.bluemarblegameco.com, www.ict.usc.edu

ABSTRACT

The purpose of this study is to explore the use of video games from the perspective of the disabled player. Over 150 participants responded to an online survey exploring the use of video games for rehabilitation. The respondents represented nine countries throughout the world. The survey consisted of questions regarding subject demographics, living situation, activities of daily living assistance requirements, use of assistive devices, and computer use. Other questions addressed the responders' disability. Video game play experience, activity, game play, controller use and accessibility are addressed. Questions regarding the use of currently available off the shelf video games in rehabilitation are explored. Lastly, we surveyed the future of video games and how they can be improved for rehabilitation and leisure enjoyment. The results of this survey are presented. In general, individuals with disabilities enjoy playing video games and play video games often. However, players with disabilities would appreciate educating the game industry about disabilities and how to make games with a more "universal game design".

1. INTRODUCTION

From June 2009- June 2010 the authors conducted the first of its kind online survey to hear from individuals with disabilities and those undergoing rehabilitation regarding their opinions of using video games for rehabilitation purposes. This is the first of a series of studies, the results of which intend to address the needs of the disabled community and to better inform game design and user interface development so as to transform how video games are developed and designed.

The world population is estimated to be 6.7 billion and disability affects 15-20% of all people, in every country, worldwide (United Nations, 2007). Today's average gamer is 34 years old and has been playing for 12 years (ESA 2010). One can assume that millions and millions of people across the globe have disabilities and play games, or wish they could. Currently, 67% of American households play computer or video games (ESA 2010; codi.buaffalo.edu) with estimations that one in five cannot play or have limited playing ability due to disabilities (Atkinson et al., 2006; KQED.com 2010). Substantial progress has been made in making games more accessible and developing more accessible user interfaces. For example, keyboard short-cuts and closed captioning are frequently employed in contemporary games. Despite these staggering statistics, many unknowns regarding the use of video games for rehabilitation purposes still exist. With the exception of the Nintendo Wii's widespread adoption in clinics over the country, deploying these enhancements into a rehabilitation setting has moved at a glacial pace. Perhaps more importantly, games are not typically designed from the ground up with rehabilitation in mind. We believe a first step in changing this is to engage people with disabilities, now! At the time of this publication, no large-scale studies have investigated games for rehabilitation from the perspective of the end-user. Using video games during rehabilitation may be an essential adjunct to making rehabilitation more beneficial.

We believe that it is imperative for the game industry as a whole to better understand the wants and needs of those with disabilities and/or undergoing rehabilitation in order to design well-informed games for rehabilitation. Therefore, the purpose of this study was to conduct an online survey exploring how individuals with disabilities play video games, what characteristics they enjoy most about video games, how they feel about using video games for rehabilitation and how to improve video games for the disabled

©2010 ICDVRAT; ISBN 978 07049 15022

population. The motivation behind the development of this survey came from a need to better understand the disabled gamer and to discover how their preferences could influence game design when developing games for rehabilitation in the future.

2. METHODS

2.1 Procedure

Many of the questions used in this survey were derived in part from the Pew Internet & American Life Project- Teens, Video Games, and Civics, September 2008. The questions were then modified or developed with consultation from a number of subject matter experts in the field of video games and disabilities. A number of avid video game players with disabilities offered their input regarding question clarity, question format and variance in responses. Fifteen participants preliminarily tested the survey; changes were made based on their feedback, and the survey was launched June 2009. The survey was conducted using Survey Monkey™ (surveymonkey.com). Only those who agreed to the informed consent were permitted to proceed to the survey. Participants under the age of 18 were required to have their parent's permission to participate in this study.

The survey began with the standard questions of location, country, gender, race/ethnicity, age, living situation, assistance required to perform activities of daily living, employment status, assistive devices, and computer/internet access at home. These questions were included so as to gain a broader perspective on gamers with disabilities worldwide. Next the survey asked about their disability: age at time of disability, descriptors of health condition, and accessibility rating scales for video games. The third page inquired about gaming experience and asked questions such as: do you consider yourself a hard-core gamer or a casual gamer?; How often do you play?; Which devices do you use?; What games do you play?; and What are your favorite games and why?. In the next phase of the survey, we were interested to explore how their health condition might affect their ability to play video games and how they interact with others while playing video games. On page five and six we explored video game enjoyment. Page seven of the survey asked for their perspective on improving video game design in general and for rehabilitation purposes and ways to improve interfaces for individuals with disabilities.

Due to the length of the survey, some questions required answers, while other questions could be skipped. Since some questions were not required, the response count varies accordingly and is listed in each table. Some questions provided space to add comments so that the participant could fully express their views regarding the question. These open-ended questions or additional comments were analyzed for themes the results of which are discussed below.

2.2 Host-websites

The survey was hosted on a number of international websites, for varying time frames, from June 2009 through June 2010. The Social Networks included Games For Rehabilitation (Games4rehab.com), Blue Marble Game Co (*bluemarblegameco.com*) Able Gamers (*ablegamers.org*), Pushrim (*pushrim.com*), LinkedIn (Games4Rehab Group, Exergame Fitness Group, The Exergame Network Group), Disability Resource Exchange (*disabilityresourceexchange.com*). Other internationally well-know websites include: Disaboom (*disaboom.com*), Paralyzed Veterans of America (*pva.org*), National Center on Physical Activity and Disability (*ncpad.com*),

2.3 Missing Data

Survey responses were not considered if they had no data. Seventy-four surveys were deleted due to missing data. We suspect that the majority of these surveys were initiated by web-crawlers as there was no data on the survey responses, a few others offered their age and location but no data beyond that and were discarded.

2.4 Analysis

For the purposes of this paper, the data collected from the survey is presented as frequency distributions. No cross-tabulations or correlations have been conducted at this point but will be conducted and published in a follow up paper in the near future.

3. RESULTS

3.1 Descriptive Statistics

Over the course of one year, 152 individuals aged (10-15) through 71-80 years old responded to this survey. With the average age for gamers reported to be 35, it is not surprising that the majority (70%) of responders

©2010 ICDVRAT; ISBN 978 07049 15022

were between 21 and 45 years old. Five participants reported that they were below the age of 18. See Table 1 for a complete description of the age distribution of this sample.

Table 1. *Age Distribution of participants (n=152)*

Age (years)	Percent Total (%)	Response Count (n)
10-15	2.0	3
16-18	1.3	2
19-20	2.6	4
21-25	13.2	20
26-30	15.8	24
31-35	15.1	23
36-40	12.5	19
41-45	13.2	20
46-50	8.6	13
51-55	7.2	11
56-60	3.3	5
61-65	2.6	4
66-70	0.7	1
71-80	2.0	3
81-90	0.0	0
> 90	0.0	0

Table 2 describes the age at which the participant became disabled. The vast majority became disabled between age 20-39 (29.4%) with the other largest group having sustained their disability before, during or at birth (19.6%). Interestingly, 29 participants indicated that they were not disabled, however in the follow-up question (Table 7) in which the subject was asked to describe their medical condition, only 23 indicated that they did not have a disability. This may be because some people with health conditions do not consider these conditions to be disabilities.

Table 2. *Age at which the participant became disabled (response count = 149)*

Age (years)	Percent Total (%)	Response Count (n)
I am not disabled	20.3	29
Before, during or at birth	19.6	28
0-4	9.1	13
5-9	3.5	5
10-19	9.8	14
20-39	29.4	42
40-59	11.2	16
60-79	1.4	2
> 80	0.0	0

As suspected given the distribution websites, the majority of responders reside in the United States (72%), with a number of participants from the UK (10.9%), Canada (7.5%) and Germany (5.4%) contributing as well. Other countries that were selected include Australia, Brazil, Mexico, Netherlands, and Turkey.

The participants who responded comprise a wide variety of race and ethnic backgrounds. Most of the responders reported themselves as Caucasian (55.3%) and Western European (23%) with Latino and European reported by 7.2% of the responders. Others reported Eastern European (4%), Native American or Alaskan Native (4%), Asian (4%), African American (2%), Pacific Islander (2%), Arabian (0.7%), Russian (0.7%) or other (Israeli, Native American, Jewish- 3.3%).

Next we asked about their living situation. Living situations could greatly influence if people can gain access to their computers/internet or if they can play video games that might benefit their physical/cognitive or psychological wellbeing. Of the 147 responders, 51% indicated that they live with spouse/significant other, while 23% live with their parents, 15% live alone, and 13% live with children. Other living situations included living with caregivers (10.2%), other family (1.4%), other adults (0.7%), group home (0.7%), foster home (0.7%) or hospital (0.7%). One respondent indicated that s/he lived in an RV behind their parent's home and considered this "basically homeless". These data indicate that many of the responders live with other people who *may* participate in assisting with game set-up or participating in game play with the person with the disability.

©2010 ICDVRAT; ISBN 978 07049 15022

With regard to performing activities of daily living, 60% of the participants perform most activities of daily living independently, while the remaining 40% require a device, personal assistance or are unable to perform the activities at all (Table 3). Data in Table 4 describes use of assistive device. Twenty one percent of the participants do not use an assistive device. However, 80% use some sort of assistive device, many of which were power wheelchairs or manual wheelchair use. These data indicate that the participants' disability varies from extremely disabled to mildly impaired.

Table 3. *Ability to perform activities of daily living (response count =145)*

	Choose not to perform	Independent	With a device	With an assistant	Unable to perform
I feed myself	1	121	6	7	13
I bathe myself	1	99	3	31	13
I groom myself	1	106	6	23	13
I dress myself	1	101	1	33	14
I do my bowel routine	2	110	1	23	9
I do my bladder care	2	110	6	19	9
I use the toilet	3	110	2	15	17
I transfer from bed to chair	2	102	6	20	13
I am mobile on level surfaces	2	106	26	3	12
I am mobile on stairs	3	75	20	11	41

Table 4. *Assistive device use (response count = 149)*

Device	Percent Total (%)	Response Count (n)
Eyeglasses	48.3	72
Power wheelchair or scooter	24.8	37
I do not use any devices	21.5	32
Manual wheelchair	18.1	27
Cane	14.1	21
Walker	8.1	12
Lower extremity Brace (AFO, KAFO)	7.4	11
Service animal	5.4	8
Upper extremity brace (splint)	4.7	7
Hearing Aid	4.0	6
Screen reader	3.4	5
White cane	3.4	5
Crutches	2.7	4
Other: Chair seat lift	1.3	2
Other: Trackball	1.3	2
Sign language interpreter	1.3	2
Telephone or video relay service	1.3	2
TTY	1.3	2
Other: assistance from others	0.7	1
Other: assistive memory device	0.7	1
Other: Back brace	0.7	1
Other: Chin switch for w/c control	0.7	1
Other: phone amplifier	0.7	1
Other: Screen enlargement software	0.7	1
Other: shower/toilet chair	0.7	1
Other: Speech communication device	0.7	1
Other: Speech recognition device	0.7	1
Other: Tutors/job coach	0.7	1
Other: Upper extremity prosthesis	0.7	1

Despite their disability and mobility impairments, most responders have been playing video games for quite some time. Nineteen percent of the responders have had their disability since birth and thus have always played despite their health condition. As expected, 51% started playing before they acquired their health-condition and only 21% began playing video games after acquiring their health condition. When asked how their health condition affects their ability to play, the responders indicated that their health condition limits the ability to play MOST games (25.4%), SOME games (21.2%), not at all (18%). Most, 68.9%, of the

©2010 ICDVRAT; ISBN 978 07049 15022

responders do not need assistance to set up the controller for game play while 31% do require assistance. When playing games, most players use a standard mouse (48.6%) or standard keyboard (42.1%) when playing video games. Other creative controllers that the participants use are graphics pen, Joystick, QuadJoy, and put the Wii controller in the mouth and moving the head.

Many participants (26.6%) indicated that on-screen text improves game play while 19.3% indicate that it is not helpful. One responder commented that "the on-screen text is usually very small and difficult to read". Another one wrote, "If I can read it before it goes away". Another one commented "It would be helpful if the size was customizable so I could change it according to my daily needs".

When asked what makes video games frustrating to play, the participants most frequently reported lack of accessible game controllers, inaccessible game play, inability to read text on screen fast enough before it goes away, inability to save, games that are time based, having to hit multiple buttons very quickly, and poor internet connections is frustrating.

3.2 Questions exploring game play

3.2.1 Do you think having an "accessibility rating scale" on video games would be helpful?

Of the 124 participants who responded, 104 answered "Yes" while 18 responded "No". This answer offered an opportunity to add comments. Sixty-one participants responded with comments falling into the following themes: An accessibility rating scale would be helpful because it would: Reduce stress, help determine if I should buy it before purchasing it, identify if it is designed/programmed for the visually impaired, would indicate if fast movements/reaction time is required to play, indicate the type of controller (keyboard+mouse, mouse only etc), length of time to complete (for focusing, memory and time sitting in wheelchair), offering information about what is challenging in the game (font size, colors, sound alerts, speed etc), information about playing with arms/legs/jumping would be useful, amount of buttons used, buying games you can't play hurts self-esteem, dexterity requirements would be useful,

Other comments opposing accessibility ratings suggested that it is impossible to create one scale that addresses all the demands of the many types of disabilities and diseases, there is no "Catch-All" criteria, perhaps a "this product has been tested on blind, deaf, and epileptic patients etc", a scale is not helpful- however providing a downloadable pdf or audio review of accessibility features through a third party would be excellent, don't limit people based on capabilities- let them figure out if they can play, what is accessible for one is impossible for another, a scale would discourage people from buying a game when they may in fact be able to play it,

One compelling response indicated that "Having a accessibility rating scale will help more than just the people born with disabilities it will help the people like our soldiers that are coming home with one arm after fighting for our country and with the way video games are starting to turn towards having your entire body involved it is leaving those of us that do not have the ability to jump or stand etc out in the dust so to speak. A rating system would just let us know ahead of time that its possible to play the game one handed or its possible to play the game from your wheelchair etc

3.2.2 What games do you play?

Of the choices provided, the games played daily include puzzle games (30%), MMOGs (22.3%), Role Playing (12.9%), Action Role Playing (11%). Most participants play games with either E-Everyone (35.7%), M(17+) Mature (30.2%), or T-Teen (27.2%) daily. When asked what were the top 3 favorite games, the two most popular games were Wii Fit (21.8%) and Solitaire (20%). Other very popular games the participants offered in the comments section included puzzle games (such as Bejeweled), first person shooter games (such as Call of Duty and Quake), strategy games (such as Civilization), console role playing games (such as Final Fantasy and Legend of Zelda), massively multiplayer online role-playing games (MMORPGs) (such as EveOnline and Warhammer), social networking games (such as Farmville), life simulation games (such as Harvest Moon and SimCity), adventure games (such as Unchartered and Tomb Raider), and music based games (such as Rock Band). Others suggested Second Life as their favorite game. The most frequently reported favorite game was Nintendo Wii Sports. When asked, "What is your favorite game of all time", a completely open ended question, the game with the most frequent response was Super Mario Brothers and World of Warcraft.

3.2.3 What do you think makes a good video game? (select all that apply)

The responders as a whole indicated that Fun Game Play (74.3%), User Friendly (69.3) and Controls were easy to use (58.4%) and Interaction from the game environment (58%) were the top 3 characteristics of a good game. Other frequently sited characteristics that more than 50% of the participants responded to include accessibility (57%), creative game play (55.4%), entertaining story line (55.4%) and entertainment value of

©2010 ICDVRAT; ISBN 978 07049 15022

playing game more than once (52%). Characteristics that fell in the bottom of the list included online game play statistics tracking (8.9%), cartoon-like graphics (11.9%), closed captioning (13.9%), graphic visuals (21.8%). Other comments suggested by the participants include physical feedback-enabled devices, ability to talk with other players, good storyline, and minimal typing requirements.

When asked about their least favorite game, the responders had much to say. The open-ended responses included: Horror, gory and gross games; games that don't let you save levels; dance games because I can't move my legs; shooting games and games where you blow things up are not fun; changing camera perspectives makes me dizzy; fast paced games because I can't keep up due to my cognitive impairment.

3.2.4 Why do you play video games?(select all that apply)

Table 5. *Why do you play video games?*

Answer Options	**Response Percent (%)**	**Response Count (n)**
Games are fun	76.8	76
It helps me to pass the time	63.6	63
I like the brain challenge	59.6	59
I like to solve puzzles	57.6	57
I enjoy escaping reality	51.5	52
Games are distracting	46.5	46
I can play with my friends	46.5	46
I like the fantasy	46.5	46
I enjoy the competition	43.4	43
I can play with my family	39.4	39
I can learn things from games	34.3	34
I enjoy the physical challenge	30.3	30
I like to put myself into the character in the game	30.3	30
I like to imagine myself in the game	28.3	28
For exercise	26.3	26
For physical rehabilitation	24.2	24
For psychological or social rehabilitation	24.2	24
I love to destroy stuff	24.2	24
To help me with my balance	28.2	18
Other	10.0	10

Additional comments offered by the participants include "I can forget that I have a disability for a while", "Video games have helped me think around the problems or issues I come across. They are also good for distracting me from needing too many pain meds because I am staying busy but not too hard physically", "[They] take focus away from my pain".

3.2.5 Do you think video games have a place in a rehabilitation setting (hospital, outpatient clinic or home)? Explain your answer.

Amazingly, 100% of the participants indicated that they believe video games have a place in rehabilitation. The main themes obtained from this question include making rehabilitation more fun, it is distracting, helps with coordination, relieves pain, increases social interaction, offers ways to improve confidence, improves cognitive function, helps with seizure disorder, depression and PTSD; and can motivate unsighted to interact with computers more.

Below are excerpts from 63 responders: "It can make rehabilitation more fun.", "Because they are fun, distracting, help pass the time, and can stimulate the mind and be therapeutic in many cases", "Yes, boring movements will be fun, its like exergaming, you have fun, you want to move. You don't feel like it is a workout or hard to do", "I know they do, I recently went to play Wii games with my friend in hospital (who is in "lockdown" can't move much of her body but her eyes, mouth occasionally and sometimes her head) we were playing hand over hand and she was enjoying it a lot, was the most animated in weeks that I have seen and I visit her daily", "Many rehabilitation exercises and activities are excessively boring. Video games can make repetitive actions much more interesting", "It takes away the boredom of hospitals and has a positive impact on rehabilitation", "anything that helps you past the time and works you brain is good", "Is a way to do some necessary Rehab that's is entertaining instead boring. Also, because one can do Rehab relating with other people", "They provide a much more entertaining context and more tangible rewards than ordinary physical therapy", "Helps coordination and adapting to disability", "I believe video games can help reaction speed, coordination, critical thinking skills and in some cases, physical strength and balance", "They can help

©2010 ICDVRAT; ISBN 978 07049 15022

people improve hand eye coordination and over come social fears", "It would REALLY help me right now to have an engaging game that could help me get stronger without overdoing it in one sitting/standing", Games can provide occupational therapy. …one of my customers needed a gaming computer for her Autistic grandson -- it was the only thing he could interact with. I've always used games for improving hand-eye coordination to train when I was a hockey goaltender", "Helps with balance, rec. therapy. coordination, stress, depression etc.", "Helps with developing coordination, brain power, and physical stamina plus being enjoyable", "It relieves PAIN playing", "Also hand / eye coordination. Or as for me.. a kind of physical therapy to lengthen my hand muscles and give me less pain", "They distract from pain (when the control doesn't cause any) and it gives me at least some form of social interaction", "amongst other things - when I am in a lot of pain, yet bored and in need of something to do but unable to really just sit and watch a tv show (too restless) a video game can distract me and actually seems to lower my pain levels - or at least keep me from focusing on them long enough for the pain meds to work", "Distraction from pain. With the right positioning I can do them even when I can't sit up. They give me something I can do with my partner. Gaming can be used to help with visual skills and hand skills", "Depending on the individual's circumstances, I think that game-playing can provide motivation, distraction, social interaction and even physio and OT, to name but a few. It can also give an individual back a great deal of confidence in themselves and their abilities", "gets them engaged SOCIALLY, helps BUILD MUSCLE in part of the body that functions, builds SELF-CONFIDENCE, engages their MIND", "Help the brain to think", "Yes, Especially in the areas of mental & physical rehab." "I can't run anymore, or practice archery like before I got sick. I can do these things in games. I think games let people experience things they can't do IRL". I think games are especially helpful to disabled children (though age is not a factor!) do some things they can't", "4 years ago I had spine surgery & was recovering from a serious accident. at the first place it was like physical therapy boot camp but the second place encouraged recreation and losing yourself in activities finding things that you enjoy to not only help you relax a bit but to help your mind heal as well. The games were simple memory games and puzzle games but it was still fun and made the rehab center not so bad the 4 months I was their unable to go home and be with family & friends", "as a combat vet of Afghanistan war, I find escaping the realities and the media and playing games is a way of distraction, and also to help with the mind, eye, and hand coordination, memory, try to improve on those skills which are hidden because of the PTSD", "Sure they are important. People need the distraction and something to do while sitting. It is engaging", "Video games can provide a way for individuals to practice all sorts of skills. The wii can be used for physical therapy, a standard video game console for OT, and the Sims for social skills training", "Anything is possible with software. It provides a safe environment for learning, therapy, and exploring ideas as much or as little as you need. Software can grow with your need, and be accessed locally", "Sometimes they can help with seizure control." "especially the Wii because of the purposeful movement factor", "Games can help with depression; can also help people gain social skills; can also help people with stress. Can even help educate people of diseases or even help medical staff further their skills within their career", "Video games can be an enjoyable adjunct to assist with physical and mental therapy. They can help PTSD sufferers distract their minds away from their trauma. They can help those that are normally cut off from society to become a part of society without the stigmas that come with their disabilities", "They could help motivate newly unsighted people to interact with computers, something they will need to do well in the 21st century", "Physical Therapy, Occupational Therapy, Speech Therapy, Recreational Therapy",

"It gives people incentive to want to be rehabilitated & gives them the will to continue to live"

Sixty-five percent of participants have never used a video game for rehabilitation purposes. Of the 35% who have, they indicated that they have used the Wii Fit, Wii Sports, Interactive Metronome, Wii Sports Resort, Balance games, Solitaire, and EA Sports Active. When asked which game was their favorite to use in rehabilitation, they responded with Wii Fit, Football, Wii Boxing, Bowling, Wii Tennis, Tilt Table, YourSelf Fitness, Wii Baseball, Dance Dance Revolution.

3.2.6 Why do you play video games in Rehabilitation? (Select all that apply).

Lastly when asked why do you play video games in rehabilitation the most frequent response was "Because they are fun" (see Table 6 for full response count).

We've used all kinds of games, from old Atari systems and the retro joy stick plug and plays to the XB360 and anything in between. With many great results reported from the Recreational therapy crew. The most impressive are the guys in for brain surgery who couldn't talk and while playing games have beat a buddy and pumped a fist into the air saying "Yes!" in triumph and not realizing that they had spoken.

©2010 ICDVRAT; ISBN 978 07049 15022

Table 6. *Why do you play video games in Rehabilitation?*

Answer Options	Response Percent (%)	Response Count (n)
Games are fun	42.6	40
For exercise	35.1	33
To help me to forget about my disability for a while	35.1	33
Games are distracting	27.7	26
I like the brain challenge	27.7	26
They motivate me to move more	26.6	25
I enjoy escaping reality	25.5	24
I enjoy the physical challenge	23.4	22
I can play with my family	21.3	20
Time seems to fly when I'm playing games	21.3	20
To help me with my balance	20.2	19
I can learn things from games	19.1	18
I like the fantasy	19.1	18
I like to solve puzzles	19.1	18
I feel less pain when I am having procedures done	18.1	17
Rehabilitation seems to fly when I'm playing games	17.0	16
I like to imagine myself in the game	16.0	15
I enjoy the competition	16.0	15
I can play with my friends	14.9	14
I love to destroy stuff	13.8	13
I like to put myself into the character in the game	8.5	8

3.2.6 Games would be more enjoyable if:

The purpose of asking this question was to understand how to improve upon the design and development of video games for individuals with disabilities and for those undergoing rehabilitation. The response that garnered the most responses was "Game developers better understood the needs of people with disabilities (63.5%). The next most frequently selected response was "The controllers were more accessible" (57.3%). Other answers selected by nearly a third of the responders included "I could use them during my rehabilitation" (31.3%), "I could use them for my daily home gym exercise routine" (31.3%), "They moved a bit more slowly so that I could achieve the goal set at each level" (30.2%), and "Scores could be equalized across disabilities so that players with different skill sets could play together while not being penalized for their impairments" (29.2%).

3.2.7. How can we make games for rehabilitation more fun?

Themes that emerged from this question included: increasing reward factor, improving accessibility, free accessible game controllers for disabled players, providing real-time data, closed captioning, remove annoying AVI toons between moves, simplify system requirements, makes games slower, offer a variety of game play speeds, add levels of difficulty/ adaptive levels, adapt more buttons, remove "judgment" from scores, make the funnier, add "cool" reinforcements for doing well, many games feel like they were created for kids- need to make some adult games for rehabilitation, improved key mapping, encourage more physical movement, use happier themes- not so much violence, provide interactivity and online competition to everyone- so that everyone could play against anyone from anywhere, maybe incorporate peoples own music likes into the games, or their own pictures as backgrounds for the games...that would make some people very happy, provide speed cheats for people with poor coordination, provide customizable control schemes so users can compensate for the hindrances of their various conditions, universal acceptance for customizable controller layouts, and finally, slow them down.

Some excerpts from these comments include:

"Design with thought that not all disabilities are equal"

"More AAA titles used in rehab settings, not just 'special' games"

"What about waving your arms to cast a spell to fight a demon? (slip the exercise into the game)"

"Make them accessible to anyone, inexpensive (being disabled leaves us with limited income and we often must decide between food, medical needs, or entertainment…entertainment comes last when you need to pay a medical bill"

©2010 ICDVRAT; ISBN 978 07049 15022

3.2.8 Please provide any further comments you have regarding games for rehabilitation and how game designers/developers can meet your wants and needs (game design, game mechanics, game interfaces, game activities etc)

This item garnered 51 responses. In general the comments focused on the following areas: better understand the disabled community through focus groups with users/caregivers/and professionals, include disabled people in the design process, increasing game accessibility, improving controllers such as sip and puff, increase size of controller buttons, make voice use easier, increase ease of moving characters on screen, customizable text, built in magnifier, making a soft controller for painful hands, create more reasonably priced motion sensors and wearable video/audio control mechanisms, make more games voice activated

> *"I think that game designers should get a research group of disabled people that have different forms and severity of disabilities so that they can at least understand better what we all need..and perhaps they can't please all of us in one game but they can make add-ons to help the visually impaired play easier or they could offer captioning or make a list of things and then let the player choose what button they want to do what task in their own game. I mean if I'm having a tough day and can't use the stick on the right side..then let me change it to the left..would that be so difficult to do???"*
>
> *"over all - there are parts of some games I love that I can't do. when my friend moved away, I have no choice but to stop playing the game*."
>
> *"Even if we had to play 10 bucks more per game, having some kind of a 'cheat code' or switch that would let us skip certain difficult (stupid) parts of the game that require coordination or speed that we just do not have to be able to progress in a game (Resident Evil 4 - i just gave up - could not do the boulder part, so the rest of the game was a waste) would be great. Even if it says 'stage skipped' or something so people don't think we got through without a hitch, just being able to bypass parts to get on with the story would be great. I *liked* everything else but that mini game killed the whole rest of the game for me. Literally - i couldn't finish it."*

Some responders offered a "Thanks" to the authors of the survey saying "this survey is a welcome addition to making gaming accessible and inclusive", "Thanks for doing this for us", "I appreciate the fact that anyone is looking at the need for games which do help with rehabilitation and thinking skills".

4. CONCLUSIONS

The results of this survey indicate that individuals with disabilities enjoy playing games and are very passionate about game accessibility and game design. While many participants had never used video games during rehabilitation, all could see their potential use and suggest that rehabilitation experts and game designers work together to improve the ways games are developed and designed to optimize use by individuals with disabilities and for rehabilitation purposes.

Future analyses of these data will assess responses based on age, gender and health condition to elucidate trends for differing health conditions or other factors that could better influence game design.

Acknowledgements: We are eternally grateful to all of the responders who generously gave of their time to complete the lengthy survey; we appreciate your perseverance and contributions. We wish to recognize Sean Kelly, Mark Barlet, Steve Spohn, Jayne Flynn, Asit Asthal and Mark Palmer for your help in the survey construction/design. We are especially thankful to all of the website hosts who graciously posted our survey and helped spread the word.

Choose all of the words that describe your health condition					
Back Pain	14.0%	20	Lupus	1.4%	2
Mobility Impairment	14.0%	20	Agoraphobia	1.4%	2
Other (please specify)	14.0%	20	Asperger Syndrome	1.4%	2
Paralysis	14.0%	20	Bipolar Disorder	1.4%	2
Chronic Illnesses	12.6%	18	Blurred Vision	1.4%	2
Spinal Cord Injury (neck/cervical C1-C8)	12.6%	18	Developmental Disabilities	1.4%	2
Depression	11.2%	16	Dwarfism	1.4%	2
Anxiety Disorder	9.1%	13	Mental Disabilities	1.4%	2
Arthritis	9.1%	13	Multiple Sclerosis (MS)	1.4%	2
Spinal Cord Injury Incomplete	9.1%	13	Obsessive Compulsive Disorder (OCD)	1.4%	2
Cerebral Palsy	7.7%	11	RSD (Reflex Sympathetic Dystrophy)	1.4%	2
Urinary Incontinence	7.7%	11	Behavioral Addiction	0.7%	1
Asthma	7.0%	10	Diverticulosis	0.7%	1
Diabetes	7.0%	10	Endometriosis	0.7%	1
Muscular Dystrophy (MD)	7.0%	10	Epilepsy	0.7%	1
Visual Impairment	7.0%	10	Familial Hemiplegic Migraines	0.7%	1
Nicotine Addiction	6.3%	9	Full Quadriplegia	0.7%	1
Pain Syndrome	6.3%	9	GERD	0.7%	1
Rheumatoid Arthitis (RA)	6.3%	9	High Cholesterol	0.7%	1
Spinal Cord Injury (Back/Thoracic T1-T12)	6.3%	9	General clumsiness/ lack o coordination!	0.7%	1
ADD/ADHD	5.6%	8	Hypertension	0.7%	1
Fibromyalgia	5.6%	8	Lyme Disease	0.7%	1
Spinal Cord Injury Complete	5.6%	8	Migraine	0.7%	1
Brain Injury	4.9%	7	Musculoskeletal problems (bad hip)	0.7%	1
Chronic Fatigue Syndrome	4.9%	7	Myasthenia Gravis	0.7%	1
Memory Loss	4.9%	7	Myasthenia Gravis, Lupus, Peripheral Nerve Hyperexcitability	0.7%	1
Acquired Brain Injury	4.2%	6	Nerve Damage	0.7%	1
Dyslexia	3.5%	5	No ACL in knee	0.7%	1
Hearing Loss	3.5%	5	Non verbal learning disability	0.7%	1
Learning Disabilities	3.5%	5	OsteoArthritis, behavioral addiction	0.7%	1
Myofascial Pain	3.5%	5	Osteogenesis Imperfecta (Brittle Bones)	0.7%	1
Osteoarthritis	3.5%	5	Paraneoplastic disorder	0.7%	1
Spinal Cord Injury (Lower Back L1-S5)	3.5%	5	Peripheral nerve hyperexcitability	0.7%	1
Stroke	3.5%	5	PTSD	0.7%	1
Amputation of the upper limbs	2.8%	4	Skin Rashes	0.7%	1
Autism	2.8%	4	Spinal Muscular Atrophy (SMA)	0.7%	1
Blindness	2.8%	4	Tendon issues / Hyperflexibility Syndrome	0.7%	1
Color Blindness	2.8%	4	Acrophobia	0.7%	1
Deafness	2.8%	4	Alcohol Addiction	0.7%	1
Hearing Impairment	2.8%	4	Amputation of the lower limbs	0.7%	1
Hypoglycemia	2.8%	4	Ankylosing Spondylitis	0.7%	1
Tinnitus (Ringing In the Ears)	2.8%	4	Dermatopolymyocytis	0.7%	1
Vertigo	2.8%	4	Diabetic Retinopathy	0.7%	1
Cancer	2.1%	3	Drug Addiction	0.7%	1
Dyscalculia	2.1%	3	Motor Neuron Disorder	0.7%	1
Head Injury	2.1%	3	Spina Bifida	0.7%	1
Parkinson's Disease	2.1%	3	Traumatic Brain Injury	0.7%	1
Phobia	2.1%	3	I Don't Have a Disability	16.1%	23
Sciatica	2.1%	3			

5. REFERENCES

M T Atkinson, S Gucukoglu, C H C Machin, A E Lawrence (2006), *Making the mainstream accessible: Redefining the game*. in *ACM SIGGRAPH Symposium on Video Games*. New York: ACM, New York

Entertainment Software Association. (2010), Available from: *www.theesa.com*.

KQED.com, *Video Games Access for All*. 2010.

United Nations, (2007), *UN Convention on Rights of Persons with Disabilities*.

School of Public Health, U.o.B. *Congressional Committee Findings for the ADA*. (2010), Available from: http://codi.buffalo.edu/Welcome.html.

©2010 ICDVRAT; ISBN 978 07049 15022

Designing engaging, playable games for rehabilitation

J W Burke[1], M D J McNeill[1], D K Charles[1], P J Morrow[1], J H Crosbie[2], S M McDonough[2]

[1]Computing and Information Engineering, University of Ulster,
Cromore Road, Coleraine, BT52 1SA UK

[2]Health and Rehabilitation Sciences Research Institute, University of Ulster,
Shore Road, Jordanstown BT37 0QB UK

burke-j5@email.ulster.ac.uk, {mdj.mcneill, dk.charles, pj.morrow, jh.crosbie, s.mcdonough}@ulster.ac.uk

[1,2]www.ulster.ac.uk

ABSTRACT

Stroke is a leading cause of severe physical disability and can result in of a range of impairments, including loss of balance, attention and concentration deficiencies, pain, weakness and paralysis. This paper reports on the design of serious games for upper limb rehabilitation following stroke. In particular, we focus on identifying principles of video game design which are important in the context of rehabilitation and show how these principles can be implemented. We also report on an evaluation of the games for playability, usability and engagement.

1. INTRODUCTION

Stroke is the leading cause of long-term disability; the World Health Organisation reports that annually some 5 million people are left permanently disabled through stroke. Stroke can often cause severe physical disability such as attention deficiency, pain, weakness and paralysis, often on one side of the body. Many hospital-based rehabilitation programmes focus on rehabilitation of the lower limb, in order to promote mobility. Our interests lie in rehabilitation of the upper limb (hand and arm), which can remain weak in up to 66% of stroke survivors. It has been shown (Wade *et al*, 1985) that early and intensive practice of active functional tasks in an enriched environment show more positive outcomes for upper limb rehabilitation. Patient motivation has also been recognised as important for therapeutic outcome and many studies have consistently linked motivation to better therapeutic outcomes (Maclean *et al*, 2000). Motivation is, however, a complex subject which has been shown to be linked to both personality traits and the social environment (Maclean *et al*, 2002).

Recently there has been a great deal of interest among health professionals in the use of computer games for rehabilitation. Video games have long been known to be engaging to play, with gamers often playing for hours at a time, seemingly unaware of the passing of time. If rehabilitation games can be created which exhibit similar high degrees of engagement it is possible that therapeutic outcome will improve. Recently, companies such as Sony and Nintendo have developed commercial games combining entertainment with exercise – for example, the Sony Eyetoy games and Nintendo Wii Fit. Research has indicated, though, that people with motor function problems can have problems playing commercial games out-of-the-box (Rand *et al*, 2004). This raises the prospect of games being designed specifically for rehabilitation.

A number of systems have been reported which use virtual environment technology for various rehabilitation applications, including phobias, post-traumatic stress disorder and motor function (upper and lower limbs). Some of these have used virtual reality technology to immerse the user in the virtual environment; others use standard display technology (computer monitors and TVs). Technology to track the user's movements is also common, particularly for motor function rehabilitation. The tracked data is often used to drive a graphical representation of the user or part of the user in the virtual environment, enabling the user to achieve a high degree of control and impact onto the virtual world. What the user does in the virtual world is clearly dependent on the rehabilitation objectives. Activity can be structured around a simulation of conventional functional-based tasks or be more game-like, where the functional tasks are couched in the

©2010 ICDVRAT; ISBN 978 07049 15022

context of a game. Several reviews have reported on published work in this area and we refer the reader to (Sveistrup, 2004) and (Weiss *et al*, 2004) for further reading.

While a number of bespoke rehabilitation systems have been built which use games to present the activity to the user, there has been little discussion of the key principles of game design that are important for this context. The aim of our work is to identify core game design principles for rehabilitation and realise these in a collection of games for rehabilitation of the upper limb motor function. In this paper we review our ideas for rehabilitation game design and detail the implementation of one of our games for upper limb motor function rehabilitation. Further, we report on the evaluation strategy for our games, focusing on playability, usability and engagement. The paper is organised as follows. In Section 2 we discuss a number of video game design principles important for rehabilitation. Section 3 details the implementation of one of the games developed by our group. Section 4 reports on evaluation of the games and conclusions appear in Section 5.

2. GAME DESIGN THEORY, ENGAGEMENT AND REHABILITATION

Video games are renowned for their ability to provoke high levels of engagement amongst game-players and Rizzo and Kim (Rizzo *et al*, 2005) suggested that the designers of rehabilitation systems could benefit from analysing the principles of game design. It has been reported that users of rehabilitation games enjoy game-like challenges (when they are present) and it would seem that these are perhaps easier to create in computer-based intervention than in traditional rehabilitation. This enjoyment may translate to improved engagement and self-motivation which are recognised as important for adherence to a programme of rehabilitation therapy. Other work in this area includes that of (Goude *et al*, 2007), who proposed a conceptual model that supports game idea generation, task design and categorisation of existing games in relation to stroke rehabilitation, but only a subset of the taxonomy is published. (Flores *et al*, 2008) criticised existing gaming scenarios for rehabilitation for being designed solely to test the overall functionality of the interface hardware and suggested that more attention needs to be given to supporting motivation for active participation. (Colombo *et al*, 2007) suggested that the difficulty level of the motor task, the awareness of the performance obtained and the quantity and quality of feedback presented to the user can influence patient motivation.

In (Burke *et al*, 2009) we identified three principles of game design which we feel have particular importance to rehabilitation: *meaningful play*, handling *failure* and setting an appropriate level of *challenge*.

Meaningful play emerges from a game in the relationship between a player's actions and the system's response. Central to creating and maintaining meaningful play is the concept of *feedback*, the methods by which the game responds to the changes or choices made by the player. Feedback can be aural (sound effects, verbal dialogue), visual (text, images, score indicators) and haptic (vibration). It is important that a user of rehabilitation games is aware of their progress towards goals (short-term and long-term) in order to achieve effective engagement.

A game responds to player actions in order that the player is aware of the impact of their actions on the game world. In this way the game encourages the player to learn what actions result in progress through the game and what actions do not. Feedback has particular importance for rehabilitation, where the concept of progress through the game may differ from that in traditional video games. Failure, for example, has always been a prominent aspect of video games, not only present but expected by players – players are often given a number of 'lives' which represent the number of chances they have to complete a task without dying. Failure to complete a task within this number of lives may result in "game over", meaning the player has to start the game (or game level) from the beginning. For motor function rehabilitation games, where the affected limbs are being mobilised, there is a risk that if the player were to experience failure during their initial play, they may attribute this failure to poor motor function and this could result in poor game engagement. Clearly this needs to be tested with users, but we suggest that failure in rehabilitation games should be handled conservatively – since engagement is a pre-requisite for positive therapeutic outcome, *all* engagement should be rewarded, at least initially. By handling failure in a positive way players may be more likely to remain engaged with the intervention. This does not mean that the game shouldn't offer challenge and drama, since these are important reasons for games being engaging in the first place.

The level of *challenge* a game offers a player is a major influence in how engaging the game is to play. Previous work has reported that users of rehabilitation games have difficulty with COTS games where the level of the environments cannot be graded (Rand *et al*, 2004). The range of motor function among people with stroke, for example, varies greatly and what might be easy for one person is impossible for another. For

©2010 ICDVRAT; ISBN 978 07049 15022

optimal engagement, games should present an ideal level of challenge for each individual player; neither too difficult that it becomes frustrating, nor too easy that it becomes boring. Traditional video games have different ways of varying challenge for players. Prior to commencement, games often ask players to select a level of difficulty, for example: easy, medium, hard, insane. This determines the pace of the game, number of enemies, number of opportunities for the player to acquire health or weapons etc. In motor function rehabilitation games the initial configuration will affect the pace, size of game elements, distance from user, etc. While data acquired from standardised assessment tests prior to game-play may help in understanding the patient's level of motor function, it is difficult to map values from these tests directly to game configuration. We have developed a configuration tool as part of our library of games where the user's range of movement is assessed using the same interaction technology as used to play the games. Data from this tool is then used to position game elements so that they are all initially reachable by the user on start-up. As the game progresses, the game adapts the challenge dynamically by changing the pace and game element positions and size, as described earlier.

As the game progresses, players will often face levels of increasing difficulty, designed to present more of a challenge as they become more familiar and skilled with the game. In commercial games, completing a level is possible only once the player understands enough of the game mechanics and has acquired the necessary knowledge and skills (including controller skills) to progress through the level to the end. Other games may not have recognisable levels as such, but the challenge might increase as particular points in the game are reached, indicating that an appropriate level of understanding and acquisition of skills has been achieved. We have investigated the use of adaptivity to automatically control the game difficulty, by altering programmable elements of the game in response to the performance of the player. For players that are struggling, the pace of the game slows and game elements become larger and easier to reach. On the other hand, for players that are coping easily with the challenge, the game speeds up, game elements become smaller and harder to reach.

3. VIDEO CAPTURE GAMES FOR STROKE REHABILITATION

Our group has designed a number of games for upper limb rehabilitation post stroke, using the principles described above. The games use a low-cost webcam to capture player movements and image analysis software to track the hand. All software was written in C# in Microsoft's XNA framework. Four games were designed in the arcade style (i.e., short, easy to learn). Two were one-handed games, where the affected limb was used to play; a third game was two handed and a fourth game was also two handed but required the hand movements to be synchronised. The user, wearing a different coloured glove or mitt on each hand, faces the computer monitor, where his/her image appears in the background (behind the rendered game elements). The different coloured gloves allow the software to track each hand's movements. To play, the user touches a game element (sprite) with either one or both hands, as appropriate for the particular game. All the games are adaptive – they get easier or harder depending on the performance of the player. To illustrate how the game design principles discussed in Section 2 were applied we discuss the design of one of the games in detail. Details of the other games can be found in (Burke *et al*, 2009) and videos can be seen at this link: *http://www.vimeo.com/4279126* . Appendix A shows screenshots of the configuration tool and the games.

In *Bubble Trouble*, a game designed to improve gross movement of the upper limb, virtual bubbles appear on the screen at random positions within the player's range of movement (as determined by the configuration tool) for a short length of time, and the goal is for the player to burst these bubbles by touching them before they disappear. The game has two variations, supporting single-handed play and two-handed play. In the single-handed version the affected limb is used. In the two-handed version, each bubble is colour-coded to match the colour of its respective glove; an arrow (pointing left or right) inside the bubble also depicts which hand the bubble should be burst with. The game has a programmable time limit (set on startup), and the number of bubbles burst within this time limit determines the player's final score. The player cannot fail in the game, rather a poor performance would be reflected with a lower score; however, messages at the end of the game are positive and encouraging regardless of the score. Distinctive and easily identifiable visual and auditory feedback is used to create meaningful play, such as a popping noise for bursting a bubble, a buzzer sound for missing bubbles, bold visual messages for hits and misses, colour coding of sprites, particle effects and score charts. Adaptivity is used to present a level of challenge suitable for the player by dynamically altering the pace, positions and size of bubbles according to the player's performance.

©2010 ICDVRAT; ISBN 978 07049 15022

4. USER EVALUATION

Although the goal for any motor function rehabilitation system must be improvement in the affected limb(s), it is necessary to run large-scale user trials over a period of several weeks in order to evaluate the effectiveness of any intervention on motor function outcome. Unfortunately this was outside the scope of the project at this time and so we elected to focus on the evaluation of the usability and playability of the games. Subsequently we identified an additional requirement to evaluate the effectiveness of the engagement quality of the games. As with the design of the games, the evaluation protocol was developed after discussion between colleagues from various departments within the University of Ulster: health and rehabilitation sciences, computer science and psychology. Approval for a 3-phase protocol was sought and granted from the University's Research Ethics Committee.

Phase 1 saw the games evaluated by 10 health people, recruited from the students and staff of the School of Computing. The games were initially demonstrated by members of the research team; the participants then played each game twice. The main instrument used to collect quantitative data was a usability and playability questionnaire (Desurvire *et al*, 2004) which was scored on a visual-analogue scale from 0 to 10. Results indicated that the majority of participants (70-80%) enjoyed all of the games. Players also felt that the games were varied, had good replay value, responded consistently and were easy to play due to the intuitive control mechanisms. More than 80% of players reported noticing that the games adapted to their performance and all liked this feature, suggesting that the games would be less enjoyable without adaptivity. One user did express the view that the change in the pace of the games when adaptivity was present was too aggressive and that the change of pace should be more 'gentle'. These results helped inform minor improvements to the games, most notably the addition of improved feedback – audio feedback and larger graphical cues when game elements were hit and missed.

Phase 2 of the study recruited 3 people with stroke from a local stroke club. One of the participants was in a wheelchair. Following demonstration by a member of the research team, participants played the games once, in their home (each game was played for 90 seconds). The same playability questionnaire was used as in Phase 1 and a further instrument for measuring self-reported exertion (Borg CR10 scale) was used. Results of this Phase were published elsewhere (Burke *et al*, 2009) but in summary all participants were successful in being able to play the games and reported that they found them challenging, fun and varied. All participants, though, reported that the adaptivity changed the pace of the games too aggressively, in particular that the games speeded up too quickly when they were performing well.

In Phase 3, 2 people with stroke were recruited to play the games for a period of 3 weeks (3 times per week). The main focus of the study was to evaluate usability, playability and engagement with the games. At the end of the intervention participants filled out the same usability and playability questionnaire as Phases 1 and 2 and also an Intrinsic Motivation Inventory (IMI) (Ryan, 1982). The IMI elicits data about a player's self-report of intrinsic motivation (which we interpret as a reliable measure of engagement). Participants also had a chance to give more general comments on their experiences. We also collected in-game data which enabled us to study patterns of scoring and gameplay speed (the average speed at which the game elements e.g., bubbles, moved). Since game elements speed up or slow down through game adaptivity, gameplay speed gives an additional measure of user performance.

Player A was a 70-year old, right-handed, female with a right hemiplegic stroke 2 years previous to the study. Her upper limb Motricity Index (Collin *et al*, 1990) scores prior to the intervention were 63 (right) and 100 (left). She generally used a wheelchair, although she was mobile with a stick at home. She was not receiving any therapy at present. The usability and playability questionnaire results indicated that the player enjoyed playing the games (rating 10 out of 10) and also found them enjoyable to replay (9/10). The player felt highly involved in the games (9/10), felt that the games responded consistently and found the feedback to be effective. She felt the controls were intuitive and that the input device was easy to use. The player also indicated that she preferred adaptive difficulty in comparison to altering the challenge manually (9/10). In-game scores and gameplay speed graphs are shown for the one-handed *Bubble Trouble* game in Appendix B below – results indicate a small rise in scores over the 3 weeks for all 4 games. Similarly, the gameplay speeds again show a small rise over the 3 weeks. Player A was generally enthusiastic and well motivated, although her limited range of movement did cause her frustration at times. She commented that the games were 'interesting, fun and encouraged me to move my arm'. Results from the Intrinsic Motivation Inventory are presented in Table 1. The interest/enjoyment subscale is considered the self-report measure of intrinsic motivation and Player A scored this as 61%.

©2010 ICDVRAT; ISBN 978 07049 15022

Player B was a 48-year old, right-handed male with a right hemiplegic stroke less than 1 year previous to the study. His upper limb MI scores prior to the intervention were 70 (right) and 100 (left). He was mobile and was not receiving any therapy at present. The usability and playability questionnaire results indicated that the player found the games enjoyable to play (8/10), replayable (9/10) and consistent (8/10) and effective (8/10) in response to the player's actions. The player did indicate that the games could have been more varied to avoid fatigue (5/10) and that games were sometimes too fast (5/10). He felt that the controls were intuitive (8/10) and that the input device (gloves) was easy to use (9/10). He also approved of the adaptivity feature (9/10). In-game scores and gameplay speed graphs are shown for one of the games in Appendix B– results indicate a small rise in scores over the 3 weeks for all 4 games. Similarly, the gameplay speeds again show a small rise over the 3 weeks. Player B was generally enthusiastic and well motivated. He commented that 'the games help me relax and know my limitations'. Results from the Intrinsic Motivation Inventory are presented in Table 1. The interest/enjoyment subscale is considered the self-report measure of intrinsic motivation and Player B scored this as 84%.

Table 1. *Intrinsic Motivation Inventory Scores.*

	Interest/enjoyment	Perceived competence	Effort/importance	Pressure/tension	Value/usefulness
Player A	61%	38%	75%	28%	75%
Player B	84%	69%	75%	25%	88%

Although both users were able to play the games, Player A self-reported perceived competence was much lower than that of Player B and this is corroborated by the graphs in Appendix B. For Bubble Trouble (one-handed) Player A's scores were in the range 77-87 compared to Player B's range 88-96. To what do we attribute the improvement in both players scores over the 3 weeks is a difficult question. There may be a learning effect, where the player gets better through familiarity with the game over time, or it could be due to an improvement in the player's motor function. Clearly larger studies, evaluating motor function before and after intervention, are required to answer this question more fully. Player A's interest/enjoyment score was also less than Player B's, though still a reasonable 61% (versus 84%) and both players rated the games value/usefulness highly (75% and 88%), their effort/importance highly (75% and 75%) and pressure/tension lowly (28% and 25%). This data would appear to indicate that both players were intrinsically motivated to continue playing the games and this was confirmed through observation by the research team.

5. CONCLUSIONS

We have presented ideas for the design of games for upper limb motor function rehabilitation following stroke. In particular we identified the concepts of meaningful play (feedback) and challenge to be particularly important for the design of games for rehabilitation. Evaluation of a number of games developed incorporating these principles show that the games were indeed usable and playable by people with stroke. Further, the games seemed to stimulate a high level of interest and enjoyment by the participants, which may indicate the games are engaging to play. We hope to conduct larger studies which would improve the generalisability of these promising early results.

6. REFERENCES

J W Burke, M D J McNeill, D K Charles, P J Morrow, J H Crosbie and S M McDonough (2009), Optimising engagement for stroke rehabilitation using serious games, The Visual Computer, 25(12), pp. 1085-1099.

C Collin and D Wade D (1990), Assessing motor impairment after stroke: a pilot reliability study, J Neurol Neurosurg Psychiatry 53(7), pp. 576-579.

R Colombo, F Pisano, A Mazzone, C Delconte, S Micera, M C Carrozza, P Dario and G Minuco (2007), Design strategies to improve patient motivation during robot-aided rehabilitation, Journal of NeuroEngineering and Rehabilitation, 4(3), pp. 33-39.

H Desurvire, M Caplan and J A Toth (2004), Using Heuristics to Evaluate the Playability of Games, Proceedings ACM SIGCHI 2004, Vienna, Austria.

©2010 ICDVRAT; ISBN 978 07049 15022

E Flores, G Tobon, E Cavallaro, F I Cavallaro, J C Perry and T Keller (2008), Improving Patient Motivation in Game Development for Motor Deficit Rehabilitation, ACM Advances in Computer Entertainment Technology, 352 pp. 381-384.

D Goude, S Björk, and M Rydmark (2007), Game Design in Virtual Reality Systems for Stroke Rehabilitation, Studies in Health Technology and Informatics, 125, pp.146-148.

N Maclean and P Pound (2000). A critical review of the concept of patient motivation in the literature on physical rehabilitation, Social Science & Medicine, 50: 495-506.

N Maclean, P Pound, C Wolfe and A Rudd (2002), The Concept of Patient Motivation: A Qualitative Analysis of Stroke Professionals' Attitudes, Stroke, 33, pp. 444-448.

D Rand, R Kizony and P L Weiss (2004), Virtual reality rehabilitation for all: Vivid GX versus Sony PlayStation II EyeToy, Proceedings of the 5th International Conference on Disability, Virtual Reality & Associated Technology, pp. 87-94.

A Rizzo and G J Kim (2005), A SWOT analysis of the field of virtual reality rehabilitation and therapy, Presence,14 pp. 119–146.

R M Ryan (1982), Control and information in the intrapersonal sphere: An extension of cognitive evaluation theory, Journal of Personality and Social Psychology, 43, pp.450-461.

H Sveistrup (2004), Motor Rehabilitation using virtual reality, Journal of NeuroEngineering and Rehabilitation, pp.1-10.

D T Wade, V A Wood and R L Hewer (1985), Recovery after stroke - the first three months, Journal of Neurology, Neurosurgery, and Psychiatry, 48, pp. 7-13.

P L Weiss, D Rand, N Katz and R Kizony (2004), Video capture virtual reality as a flexible and effective rehabilitation tool, Journal of NeuroEngineering and Rehabilitation, pp.1:12

Appendix A: screenshots of the games

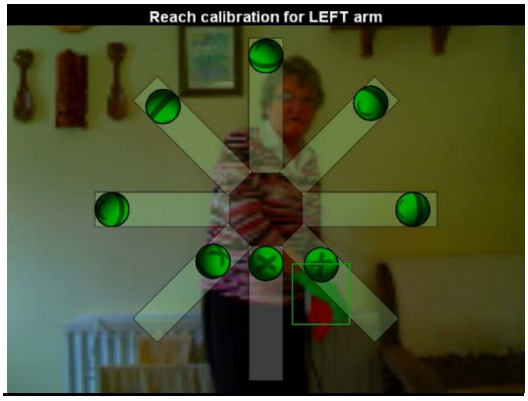


Image 1. *Range-of-movement configuration.*

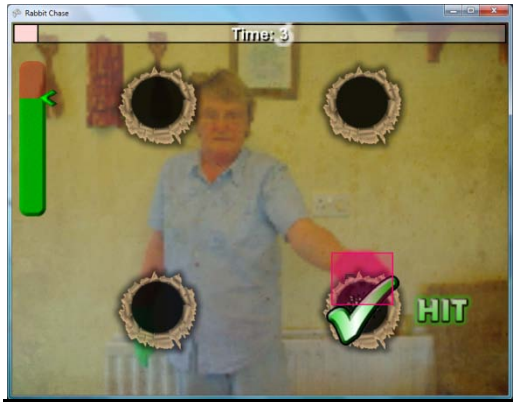


Image 2. *"Rabbit Chase", one handed game.*

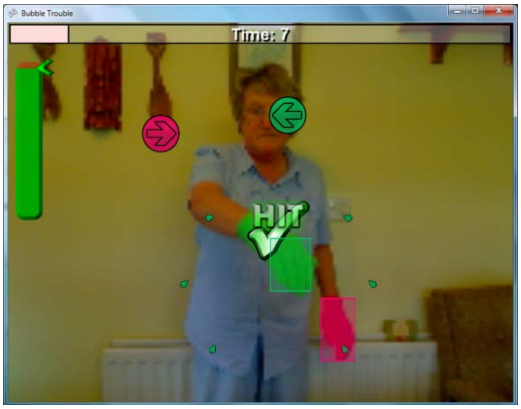
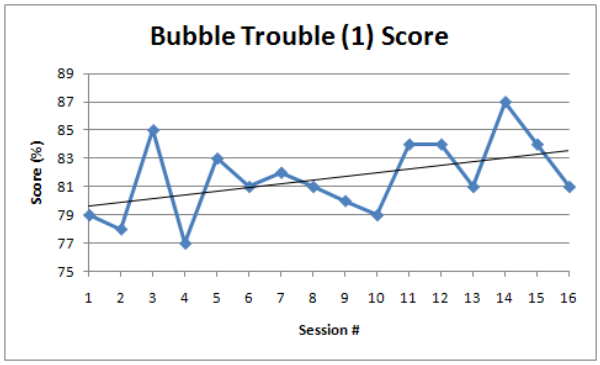


Image 3. *"Bubble Trouble" (Two handed version).*

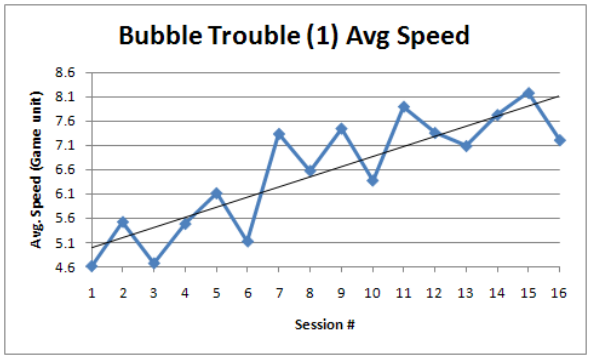
Image 4. *"Arrow Attack", two handed game.*

©2010 ICDVRAT; ISBN 978 07049 15022

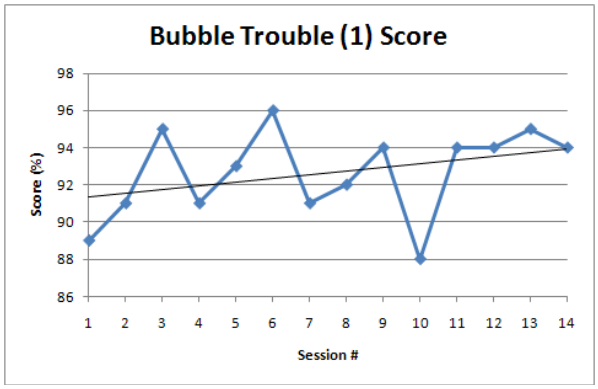
Appendix B: Games Scores and Play Speeds



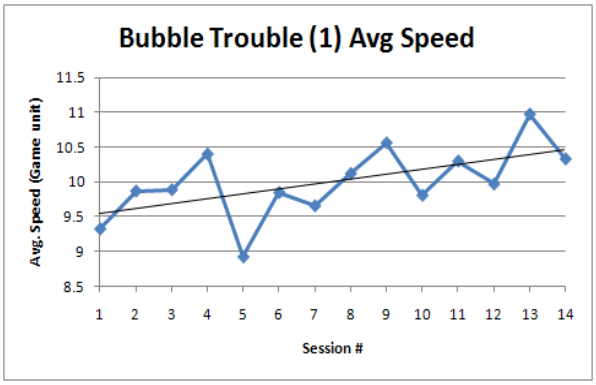
Patient A scores for Bubble Trouble game



Patient A game speed for Bubble Trouble game



Patient B scores for Bubble Trouble game



Patient B game speed for Bubble Trouble game

©2010 ICDVRAT; ISBN 978 07049 15022

Designing studies for the requirements and modelling of users for an accessible set-top box

P M Langdon[1], M F Gonzalez[2], P Biswas[3]

[1,3]Engineering Department, University of Cambridge, UK,
Trumpington Street, Cambridge, UK

[2]INGEMA, Ingema Grupo Matia,
Camino de los Pinos, 20018, San Sebastian, Spain.

[1,3]*pml24@eng.cam.ac.uk, pb400@eng.cam.ac.uk,* [2]*mari.gonzalez@ingema.esc*

[1]*www-edc.eng.cam.ac.uk,* [2]*www.ingema.es*

ABSTRACT

This paper describes work carried out to address the human centred design process behind the generation of requirements and user data for the prototyping of a user-model intended as part of a TV set-top box intended for use by mild to moderately impaired users. The aim is to develop both the technology and user modelling required within one STB system that will enable individuals with sensory, cognitive and physical impairments to interact with a number of reference applications. In order to do this it will be necessary for the system to categorise users on the basis of their input and interaction performance with a variety of input devices and assign them to a pre-assigned profile in the systems internal user-model. We address the issue of whether a human centred design process can be developed that is in principle capable of adequately generating the required data and specifications. We report the development of an inclusive design approach which subsumes both accessibility and usability. The ultimate aim will be to create a foundation for actual research and development work by identification of requirements from users as well as application and framework developers. We report the requirements analysis of this development and some preliminary results from user focus groups, chosen using an inclusive survey of capability, and interacting with early prototypes of interaction interfaces.

1. INTRODUCTION

This paper describes work carried out to address the human centred design process behind the generation of requirements and user data for the prototyping of a user-model intended as part of a TV set-top box intended for use by mild to moderately impaired users (Pirkl, 1993, Keates, 2004).

The design and prototyping of this approach is the remit of the EU FP7 project: Gentle User Interfaces for Disabled and Elderly Citizens (GUIDE DoW, 2009). The aim is to develop both the technology and user modelling required within one STB system that will enable individuals with sensory, cognitive and physical impairments to interact with a number of reference applications. In order to do this it will be necessary for the system to categorise users on the basis of their interaction performance with a variety of input devices and assign them to a pre-assigned profile in the system's internal user-model. This model will then adjust the output modalities and interaction elements to present the interaction most suited to the user's capabilities within the broad envelope of mild to moderate impairment. The system will be capable of presenting sound, speech, visual, haptic displays, (Langdon, Hwang, Keates, Clarkson and Robinson, 2002) and will be controllable using pointing devices, gyroscopic inputs, gestural and voice commands as well as hand-held controllers and touch screens. The GUIDE displays will utilise multimodal interfaces exploiting multimodal advantages, avatars and accessible displays in order to cater for the range of impairments and their co-occurrence (Duarte and Carrico, 2006).

1.1 Research Question

Although the GUIDE description of work specifies the work-packages, deliverables and time table, it does not address the necessary design process and required data collection and interaction testing required to

©2010 ICDVRAT; ISBN 978 07049 15022

achieve the GUIDE user model and technology specifications.

We address the issue of whether a human centred design process can be developed that is in principle capable of adequately generating the required data and specifications. Once user data has been collected it will be analysed and presented by way of empirical verification of the design process and concept. The use of a design based approach to technology development for inclusive design will be thereby tested. Final validation will test the effectiveness of the GUIDE system in user trials.

The fundamental basis of the GUIDE user-centred design is inclusive (Langdon, Clarkson and Robinson, 2008). Furthermore the project can be characterised as a design exercise that configures the necessary technology and research that will be required to deliver working prototypes of hardware and software, a hand-book or manual for its use and for development of software that will run on the system. Hence the process may be characterised as based on Inclusive Design (Clarkson, Coleman, Keats, Lebbon, 2003).

GUIDE will adopt an inclusive design approach which subsumes both accessibility and usability. It proscribes a holistic approach to the entire population age range for accessibility as well as for the disabled. It further addresses usability for the disabled and the ageing by specifically requiring usability to be addressed as an interaction between actual product features and user capability ranges (Waller, Langdon and Clarkson, 2008):

"The design of mainstream products and/or services that are accessible to, and usable by, people with the widest range of abilities within the widest range of situations without the need for special adaptation or design"- British Standards Institute (BS 7000-6:2005).

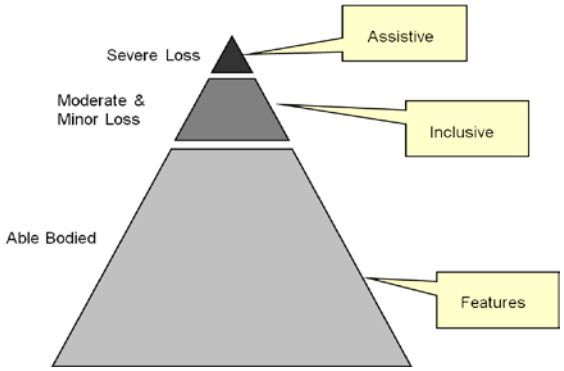


Figure 1. *The Inclusive Design Pyramid.*

1.2 Aims and Goals

Although the project will require many activities and deliverables, a working design and plan was required to enable the human factors and gerontologists and other technological partners to operate together in an integrated way to deliver the right data, models and activities in a well-coordinated way. The ultimate aim will be to create a foundation for actual research and development work by identification of requirements from users as well as application and framework developers. The design goal will be the elements and components of the Guide User Model (GUM) in the form of clustered personas and profiles along with an algorithm and data structure that can support its use in the GUIDE technology system. The GUIDE human-centred design process is based on three concentric iterations of requirements implementation and trials that will be carried out over the duration of the entire project with increasing levels of technologic fidelity and readiness of the human interface.

The research programme may be described as both an investigation and a design process. Figure 2 is concerned with describing the key issues and planning and design for the initial user studies, specifically what activities, methods, data and analysis will be required to deliver the GUIDE user model and prototypes of the GUIDE framework. This corresponds to the inner ring of the human centred design process and is intended to deliver data and early prototypes within the space of one year.

©2010 ICDVRAT; ISBN 978 07049 15022

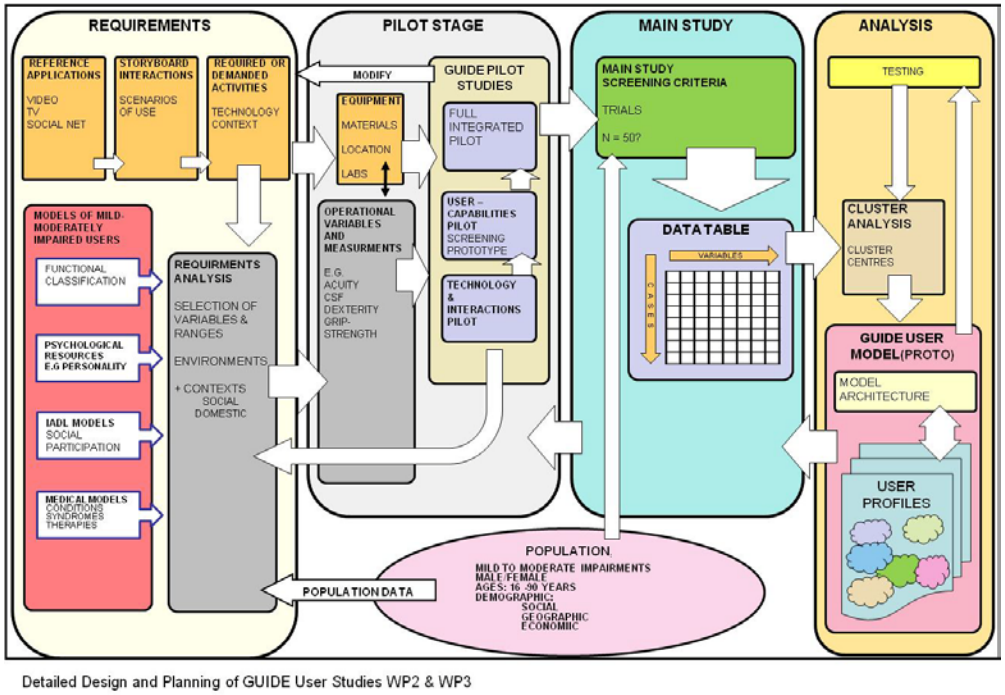


Figure 2. *The GUIDE human Centred Design process.*

2. PROPOSED DESIGN AND PLANNING OVERVIEW OF USER STUDIES

Referring to Figure 2, the designed process will be divided into 4 main stages:

- *Requirements*
- *Pilot Stage*
- *Main Study*
- *Analysis and Model Specification*

Each of these will be described separately and each section refers to a section of the schematic.

2.1 Requirements Stage

The requirements analysis will take as its starting point three main sources of information. These will firstly be the technical interface specifications for the reference applications, incusing their technologies and contexts and secondly the requirements sources from adopted models of mild-moderately impaired users. The third source of information will be the population data taken from existing sources.

2.2 Requirements analysis

The analysis stage will take as input the basic interactions, storyboards and scenarios of the reference applications and technology contexts and combine them with the chosen variables of importance from the various models of impaired users that guide adopts in the contexts of use that are anticipated. These requirements will be used as input to the next pilot studies stage.

2.3 Technical interfaces

The reference applications consist of a set of applications with a simplified set of essential basic Interactions and constraints (ISO 13407, 1999). The applications were chosen to exploit fully interactive TV capability and to provide opportunities for multimodality. An initialisation “application” designed to allocate a user new to the GUIDE system was necessary. This has the main function of performing a first pass through some tests of visual, hearing and movement capability to form a preliminary classification of the user to GUIDE profiles in a manner sensitive to on-technical or technology fearing users.

- *Initialisation of new users.* Assigns a new user to a GUIDE profile in user-friendly way.
- *TVNow.* An electronic programme guide
- *Telelearning*
- *Home Automation*

©2010 ICDVRAT; ISBN 978 07049 15022

- *Videoconferencing*

It was necessary to define the activity requirements of the reference applications without considerations of capability. These case definitions will then be used to develop the usage cases and scenarios of use based on expected application contexts. Finally, it will be necessary to Specify I/O devices, modes and ranges of flexibility that will be specific to each reference application. This information will feed into the Requirements analysis.

2.4 Models of the User

GUIDE has adopted requirements from several models of the user. These include:

- *Data from functional classification* systems for human capability classified according to mild-to moderate impairment. Functional capability models and data (Persad, Langdon and Clarkson, 2007). For example: 1) cognitive capabilities such as memory, reasoning, attention, working memory, speed of processing; 2) Qualitative and Quantitative ranges of data; 3) Ranges: age, gender, perceptual, cognitive and physical-motion, (Schaie, 1988; Rabbitt, 1993);
- *Data relating to human psychological resources* as derived from gerontological principles such as personality type and indices of self-efficacy etc. Quality of life; models of Needs, Wants, Pleasures and Joys, (Fisk *et al*. 2004);
- *Data from Instrumental Activities of Daily Living* as researched in Gerontology, for example cooking, communication, mobility and social participation etc. e.g. Specific ADL and IADL difficulties (Lawton and Brody, (1969);
- *Data from medical, practitioner and social models of disability*, including conditions, symptoms, syndromes, therapies rehabilitation requirements and carer relationships and requirements. E.g.: 1) Social class, geography and affiliations; 2) Social context groups (home vs. independent living vs. care).
- *The requirements of the algorithmic GUIDE User Model* and its architecture (data quantity, algorithms and format);
- *Population Data.* It should be noted that the ultimate source of such data will be the population data regarding impairment, disability and handicap. The models will specify the type of data to be included in the requirements.

2.5 Population Data

Statistical and survey data regarding human capability have been used to formulate requirements. This will include variation with respect to gender, age and demography, where demography should include geographical location, social context and specifications, economic information and other sources of data such as models of ageing from medical statistics (Waller, Langdon and Clarkson, 2008).

2.6 The Pilot Stage

The approach here has been to define a simple design space with simplified interaction for proof-of-concept tests that define the activity requirements of the reference applications. The outputs of the requirements analysis are general variables and objective measurements of theoretical and practical utility. This has been completed in the form of a survey of user participants that will form the pool of users for the main GUIDE user study. More than 100 survey items, based on theoretical models, have been used to collect self-report and subjective data in conjunction with objective measurements of vision, hearing and cognitive and physical capability.

On the basis of this operationalised set of variables, a number of pilot studies were carried out in order to specify the final set of measurements and variables that will be collected in the main GUIDE user study. The aim has been to carry out a fully integrated pilot study with a small number of representative users (n = 5-15). These pilot studies have been carried out at the most suitable sites given the distribution of equipment and materials and access to suitable participants. An important part of the pilot trials is continuous feedback and modification of technology, capability and context and scenario information to the requirements stage, allowing optimisation of practical considerations and reduction of management risk (failure to obtain a useful or complete user model for the next stages of the GUIDE project). It has allowed further initial insights on the viability of the multimodal user interfaces for particular impairments, by way of early prototypes and initial user studies. It is also necessary that the results of these pilot studies will assist the specification of the architecture and processes for the usable framework that the ICT developer will interact with.

2.7 Main Study

The main study will consist of trials with around 50-100 participants chosen on the basis of the full integrated

©2010 ICDVRAT; ISBN 978 07049 15022

pilot and using the operational variables and measurements from the requirements analysis. These will enable screening of trial participants to give a sample that is controlled and stratified to reflect the anticipated user groups from the main population. The main study will require all the available technology expected for use in GUIDE along with usage scenarios of use and personas from the models of users. Running 50-100 users should yield sufficient data for an accurate cluster analysis but it should be noted that if the number of variables is large that the number of participants (cases) may need to be greater for statistical reasons. These trials should take around 12-16 weeks.

2.8 Analysis and Model Specification for the Prototype User Model

As part of separate work, it has been necessary to research and design the structure of the GUIDE User Model. This includes its underlying principles, algorithms and implementation. Important considerations will be the scope of the model, representations, processes and data structures and modes of adaption (Biswas and Robinson, 2008). Adaption between profiles will use advanced statistical state-space estimation techniques; (Godsill, Doucet and West, 2004) and advanced user modelling. However, for the purposes of this part of the GUIDE programme it will only be necessary to specify the guide user profiles as the end-point of the entire requirements specification and user study process. At minimum it is expected that there will be

- A clustered set of user profiles;
- A model architecture to reference and access the profiles;
- The results of a testing and validation process.

Further validation of the model will then take place in further continued user-centred design processes in GUIDE. In particular it will be necessary to show that the user model can predict and accommodate users who use the prototypes and that the match of random users' capabilities to the framework performance is close and appropriate. Only limited feedback to the results of the main study will be possible at this stage.

2.9 User Adaption

The user initiates interacting with the system after properly configuring it. The configuration stage selects the appropriate modality of interaction. After configuration the user keeps on interacting with the system and the system dynamically adapts its responses. Finally after the interaction, the system updates the user profile based on the history of the interaction. The detail of the configuration stage is given in the following activity and sequence diagrams. It consists of evaluating the range of ability of the user through a battery of tests and uses that information to select the appropriate modality of interaction based on a user model. We have assumed in these figures that our user can use his vision and speech to some extent, can hear sound and can also move body parts. After the user finishes interacting with the system, the system analyzes the history of interaction and updates the user profile to give better adaptation next time. The interaction stage can be explained with the help of Norman's model of seven stages of action (Norman, 1988). The user initially perceives the present state of the system. Based on their intention, the user then decides to perform an action and converts it into a device operation. When the system gets an input from the user, it adapts its response based on the user model to reduce the gulfs between execution and evaluation. Finally the system changes its state and the user perceives this new state and continues to interact.

There will be mainly two forms of adaptation:

- Static adaptation which is personalisation before the user starts interaction;
- Dynamic adaptation that is personalisation following the interaction pattern, such as calculating error rate, user idle time from the usage log, with the system.

The adaptation mechanism will be based on the GUIDE user models. A user model is a representation of the knowledge and preferences of users (Benyon and Murray, 1993). Three main types of user model are in widespread use:

- The GOMS family of models, which were developed only for human computer interaction (HCI);
- Models involving cognitive architectures, which take a detailed view of human cognition;
- Application specific models.

The GOMS (Goal, Operator, Model, Selection) family of HCI models (e.g. KLM, CMN-GOMS,CPM-GOMS) is mainly suitable for modelling the optimal (skilled) behaviour of users. On the other hand, models developed using cognitive architectures consider the uncertainty of human behaviour in detail but have not been widely adopted for simulating HCI as their use demands a detailed knowledge of psychology. Application specific models are developed by keeping only a single application in mind and so they are hardly usable to model human performance in general. There is also not much reported work on systematic modelling of assistive interfaces. A more detailed discussion on user modelling can be found at reference

©2010 ICDVRAT; ISBN 978 07049 15022

[Biswas, 2010]. The GUIDE user model will try to solve the problems of existing user modelling techniques. It will work based on the following four stages:

- Data collection: Initially we collect data from a lot of users with different range of abilities to develop the initial user profile;
- Cluster analysis: The data will be clustered to summarize users' impairments and disabilities into groups;
- Mapping interface parameters to user profiles: The interface parameters for different scenarios of interactions will be related to the levels of abilities of users;
- Interface personalization: Finally the interfaces will be personalized according to the relationships established at the previous stage.

3. PRELIMINARY FOCUS GROUPS

A set of preliminary focus groups have been carried out using six participants with a range of capabilities from low to sever impairment in specific functional capability areas.

P1	F Age 41	Visual impairment 10% capability, technology literate - special glasses for TV.
P2	M age 75	Visual impairment 10% capability,y technology literate
P3	F age 70	Mobility impaired leg and elbow (ROM problem), not technology literate (used vid conf with son) . No glasses.
P4	F age75	Memory problems (age related) not technology literate. No glasses.
P5	F age 74	Mobility and hearing impairment, not technology literate. No glasses.
P6	F age 80 -	Objective memory problem (measured) with visual and verbal memory. Glasses

Table 1. *Participants of early user Focus groups*

3.1. Results of Focus Groups

The focus groups were carried out using successive presentation of a scripted sequence of simulation slides followed by questions for stimulating discussion. Tests started with presentation of the speaking GUIDE avatar and an introduction to the system. Subsequent tests examined the response of participants to automated changing of text size, pointing to select items, speech control and combinations of pointing and speech control.

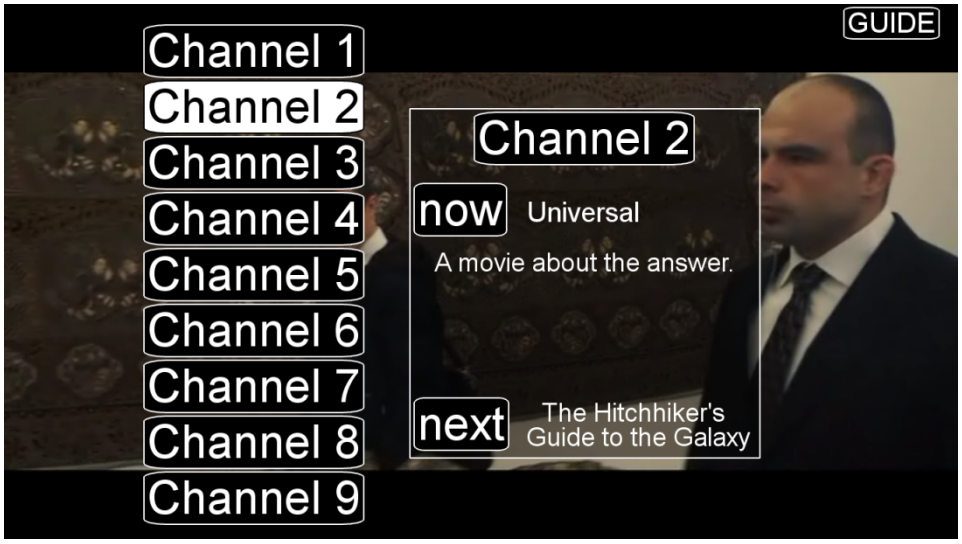


Figure 3. *The working mock-up of the Programme Guide*

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

3.1.1. Initialization Scenario

- *Do you know what an Avatar is? Do you have another name for it? Do you prefer to see only the head or whole body?*

  No participant knew what an avatar was so they could not say what they thought about it or if they prefer it with body or just a head. Two preferred the avatar with body (AAMI and Mobility disability) and also they would like it to be really expressive. All commented they would like a different avatar. Both of the avatars were not appealing for them but they did not give a reason why. They want them to be more attractive and realistic.

- *Do you feel comfortable if the system decides to test what is the appropriate letter size or would you prefer that you leave her alone?* Would you like to do the test after you ask if the letter is correct and so you say so?

  Everybody wanted that the system selects them the appropriate letter size. All of them considered appropriate to test the avatar to suit the user and they believe it is necessary that the avatar ask a second time to confirm this, if it is more appropriate.

- *Do you like the idea of selecting something by pointing and saying at the same time? Would you like to use one of two ways?*

  Everyone felt the need to use multiple modalities when deciding to choose an item. They preferred to select it and say it at once. All of them thought this was better than the TV remote control. They thought it could be difficult to succeed with gestures so they preferred verbal mode, specially those with visual and mobility disability.

- *If you had noticed it, would you like to see an arrow to point to what you are confirmed?*

  Yes, they felt it was necessary to use an arrow and illuminate what was selected.

- *Do you find it helpful to change the channel with a gesture?*

  All considered that it could be confusing to select what you want to see using only a gesture. People with visual disability raised the issue of whether it was possible to choose (for several days) the mode you want to use to select a channel. The modalities that they preferred were: verbal, pointing and gestures (in that order).

- *Do you like the possibility of seeing the same content using different forms?*

  Yes, they find it very nice to see the same content presented using different modalities. One person with mobility disability did not like the idea of changing the form of what you are seeing according another the criteria of another person who was present. She felt it could cause family problems.

3.1.2. Home automation

- *What does it mean for you to have a "home automation and modern infrastructure"?*

  This was interpreted as meaning that you do not have to do the such as housework). The use of shutters that rise and fall according to the light were seen as a positive example once this was established.

- *What kind of assistive technologies do you know of?*

  A number of applications were mentioned, including tele-alarm; cooking pots going off when they reach a temperature; ceramic hobs that turn off when spillage occurs, robots that cook and clean.

- *What do you think about what technology support in the various activities of daily living? Considering your capabilities, do you think such a device can help you? How do you think a system like this can help?*

  Nobody had support technologies. They believed that although they have some kind of technology, people are always going to depend on others. They preferred to have a person at home with a new device because they are often different problems that the technology cannot resolve. Some of them commented (AAMI, Mobility) that people who use technology at home would spend all of their time indoors and this could be a problem. Two of them (AAMI) thought that having the system would make them more dependent of it and then be more lazy.

- *Depending on your capabilities, how do you think the system should show reminders and notices?*

  All participants preferred to hear a noise (for example an auditory alarm when they leave the oven on) instead of a note in the TV. They thought this was a bad idea, because most people would have the TV off or they would not read the note if they are looking elsewhere.

©2010 ICDVRAT; ISBN 978 07049 15022

- *What is your opinion on the automation system at home? What are the possible problems of this device?*

  One of the main problems expressed was that if the system did not work then you could not get outside your home. Those with visual disability thought that it would be better if the system had a robbery alarm system.

- *Can you imagine having this device at home? How could you increase your sense of security?*

  All users agreed that they would have this at home and that it could increase their sense of security through remote control.

3.1.3. Video conferencing

[No specific questions were recorded for the following applications]

- They did not have experience with computers or video-conferencing and chat systems. Only one person had used the internet before but only through being assisted by her family.
- They preferred to use their voice to make a phone call or to hang up the phone, but they did not want to use hands to make gestures.
- They liked that the avatar but only in the context of education. They especially liked the idea of seeing their relatives on the screen simultaneously. They thought this was charming and improved relationship by making people seem closer.
- Two modalities (speech and gyroscopic pointing) were always preferred together, instead of alone, particularly when difficulties were experienced with the volume.
- In general, they found it a useful, entertaining and different system when compared to the telephone. They like the possibility of talking to several people at the same time. They wanted to know if the other contacts of their list must have also the device.

3.1.4. TV Now

- The participants do not think this application is useful for people who have memory problems. Also they think the avatar is annoying and it would be tiring for the person. It would not help the user and they argued it could even be more difficult for AAMI people.
- They do not think this application is for these kind of people maybe only with elderly people with slight memory problems. So they think that it would be better if the instructions are easy and clearer.

3.1.5. Tele-learning

- The tablet was greatly enjoyed because it was comfortable and can move it with you. One person with Age Associated memory Impairment (AAMI) thought this could be a problem because you may forget where it is.
- Two participants with visual disability thought that it was good to have it in the hands so you can place it closer during use.
- The idea of making a circular touch gesture to ask for help was generally considered difficult so they preferred speech input.
- The instructions for use were adequate. The signs to proceed or return to the menu were good but two participants proposed to make it clearer with text captions (back, pause).
- Different opinions were expressed with this application. One of them with a visual disability wanted to see less cluttered information in the class preferring to see the relevant information of the slides and the text content. Two participants with (AAMI) wanted to see the lecturer in a primary display and the content of the slides in a secondary area. One participant with auditory impairment preferred to see the text content as the main presentation and the lecturer in a second area.

4. SUMMARY AND CONCLUSIONS

We have described the proposed design process for the requirements and technology specification of an accessible set-top box usable by the mild to moderately impaired users. The proposed design approach combines human-centred design philosophy with principles of Inclusive Design and Engineering Design methods.

The process will be verified and tested by:

- An analysis of the effectiveness of the requirements developed from the pilot process;
- An analysis of the effectiveness of the user profiles arrived at for the pilot studies prior to collection of

©2010 ICDVRAT; ISBN 978 07049 15022

data from a larger group for 50 – 100 users;

- The adequacy of the data collected during the technology interaction prototyping pilot studies.

The criteria for success will be the extent to which the combined interactions and adaptive model accommodates the range of impairments and capabilities that users can deploy during the interactions required to use the reference applications. Preliminary Focus groups and experimental trials with low-fidelity prototypes and mock-ups have already yielded insights into the users' preferences and likings for specific multimodal interaction styles. Each future participant undergoes a survey of their subjective, self-report preferences, background and objective measures of capability including, vision, hearing, movement and cognitive capability. These two sources of data, survey and experimental pilot trials are being used together to identify key areas of multi-modal interaction that interact with specific capability variation in order to to define priorities for interface development.

Acknowledgements: This work has been carried out under EU FP7, ICT-2009.7.2 Grant agreement no: 248893.

5. REFERENCES

Benyon D. and Murray D. "Applying User Modeling to Human Computer Interaction Design."

Artificial Intelligence Review 7.3 (1993): 199-225.

Biswas, P., and Robinson, P., 2008, A case study in simulated HCI for special needs.,In Langdon, P., Clarkson, P.J., , and Robinson, P., (2008) Designing Inclusive Futures, Springer-Verlag London, ISBN, 978-1-84800-211-1.

Clarkson PJ, Coleman R, Keates S, Lebbon C (Eds) (2003), Inclusive Design: design for the whole population, Springer-Verlag, London.

Clarkson PJ, Coleman R, Keates S, Lebbon C (Eds) (2003), Inclusive Design: design for the whole population, Springer-Verlag, London.

Duarte, C., Carriço, L. (2006) A Conceptual Framework for Developing Adaptive Multimodal Applications. In Proceedings of IUI'2006, 11th International Conference on Intelligent User Interfaces, Sydney, Australia, pp. 132-139, ACM Press, January, 2006.

A. D. Fisk, W. A. Rogers, N. Charness, S. J. Czaja, and J. Sharit. Designing for Older Adults. CRC, 2004.

GUIDE DoW., GUIDE (FP7-248893) Annex 1, version 0.98 of 4 Sept. 2009.

Godsill S.J., Doucet A. and West M.. Monte Carlo Smoothing for nonlinear time series. Journal of the American Statistical Association. Vol.50, pp. 438-449, 2004.

ISO 13407. Human-centred design processes for interactive system (ISO 13407:1999) ISO Standard, 1999.

Keates, S. and Clarkson, P.J. (2004) 'Assessing the accessibility of digital television set-top boxes' in Designing a more inclusive world, 183-19.

Langdon, P., Clarkson, P.J. and Robinson, P. (2007) 'Designing accessible technology' in Universal Access in the Information Society, 6 (2), 117-217 (1615-5289).

LAWTON , M.P. & BRODY, E.M. (1969). Assessment of older people: self-maintaining and instrumental activities of daily living. Gerontologist, vol. 9, pp. 179-185.

Langdon, P.M., Hwang, F., Keates, S., Clarkson, P.J. and Robinson, P. (2002) 'Developing assistive interfaces for motion-impaired users using cursor movement analysis in conjunction with haptic feedback' in (ICDVRAT) 2002, Veszprem, Hungary, 223-230.

Norman D., The Psychology of Everyday Things, Basic Books (1988),USA

Persad, U., Langdon, P., Clarkson, P.J.: Characterising user capabilities to support inclusive design evaluation.Int. J. Universal Access Information Society 6(2):119-135 (2007).

Schaie, K.W., (1988), Variability in Cognitive Functions in the Elderly: implications for societal participation. Basic Life Science, v43, pp191-211.

Pirkl, J., (1993) Transgenerational Design: Products for an ageing population, Van Nostrand Reinhold, NY.

Rabbitt, P.M.A., (1993), "Does it all go together when it goes? The Nineteenth Bartlett Memorial Lecture." The Quarterly Journal of Experimental Psychology 46A, (3): pp385-434.

Waller, S.D., Langdon, P.M. and Clarkson, P.J. (2008) 'Converting disability data into a format suitable for estimating design exclusion' in Designing inclusive futures, 3-14.

©2010 ICDVRAT; ISBN 978 07049 15022

SimCoach: an intelligent virtual human system for providing healthcare information and support

A Rizzo[1], B Lange[1], J G Buckwalter[1], E Forbell[1], J Kim[1], K Sagae[1], J Williams[1], J Difede[2], B O Rothbaum[3], G Reger[4], T Parsons[1], P Kenny[1]

[1]Institute for Creative Technologies, University of Southern California
12015 Waterfront Dr., Playa Vista, CA., USA

[2]Weill Medical College of Cornell University
525 East 68th Street, New York City, N.Y., USA

[3]Dept. of Psychiatry, Emory University School of Medicine
1841 Clifton Road, NE, Atlanta, GA., USA

[4]National Center for Telehealth and Technology (T2)
9933 West Hayes Street, OMAMC, Joint Base Lewis-McChord, Tacoma, WA., USA

arizzo@usc.edu, bslange@gmail.com, jgbuckwalter@ict.usc.edu, forbell@ict.usc.edu, kim@ict.usc.edu, sagae@ict.usc.edu, williamsj@ict.usc.edu, jdifede@med.cornell.edu, brothba@emory.edu, greg.reger@us.army.mil, tparsons@ict.usc.edu

[1]*http://ict.usc.edu/*

ABSTRACT

Over the last 15 years, a virtual revolution has taken place in the use of Virtual Reality simulation technology for clinical purposes. Recent shifts in the social and scientific landscape have now set the stage for the next major movement in Clinical Virtual Reality with the "birth" of intelligent virtual humans. This paper will present an overview of the SimCoach project that aims to develop virtual human support agents to serve as online guides for promoting access to psychological healthcare information and for assisting military personnel and family members in breaking down barriers to initiating care. While we believe that the use of virtual humans to serve the role of virtual therapists is still fraught with both technical and ethical concerns, the SimCoach project does not aim to become a "doc in box". Rather, the SimCoach experience is being designed to attract and engage military Service Members, Veterans and their significant others who might not otherwise seek help with a live healthcare provider. It is expected that this experience will motivate users to take the first step – to empower themselves to seek advice and information regarding their healthcare (e.g., psychological health, traumatic brain injury, addiction, etc.) and general personal welfare (i.e., other non-medical stressors such as economic or relationship issues) – and encourage them to take the next step towards seeking other, more formal resources if needed.

1. INTRODUCTION

Over the last 15 years, a virtual revolution has taken place in the use of simulation technology for clinical purposes. Technological advances in the areas of computation speed and power, graphics and image rendering, display systems, tracking, interface technology, haptic devices, authoring software and artificial intelligence have supported the creation of low-cost and usable PC-based Virtual Reality (VR) systems. At the same time, a determined and expanding cadre of researchers and clinicians have not only recognized the potential impact of VR technology, but have now generated a significant research literature that documents the many clinical targets where VR can add value over traditional assessment and intervention approaches (Holden, 2005; Parsons & Rizzo, 2008; Powers & Emmelkamp, 2008; Rose, Brooks & Rizzo, 2005; Riva, 2005). This convergence of the exponential advances in underlying VR enabling technologies with a growing body of clinical research and experience has fueled the evolution of the discipline of Clinical Virtual Reality. And this state of affairs now stands to transform the vision of future clinical practice and research in the disciplines of psychology, medicine, neuroscience, physical and occupational therapy, and in the many allied health fields that address the therapeutic needs of those with clinical disorders.

©2010 ICDVRAT; ISBN 978 07049 15022

Concurrent with the emerging acknowledgement of the unique value of Clinical VR by scientists and clinicians, has come a growing awareness of its potential relevance and impact by the general public. While much of this recognition may be due to the high visibility of digital 3D games, the Ninetendo Wii, and massive shared internet-based virtual worlds (World of Warcraft, Halo and 2nd Life), the public consciousness is also routinely exposed to popular media reports on clinical and research VR applications. This evolving public awareness coupled with a growing body of evidence as to the added value of simulation technology has brought the field of Clinical VR past the point where skeptics can be taken seriously when they characterize Virtual Reality as a "fad technology".

These shifts in the social and scientific landscape have now set the stage for the next major movement in Clinical VR. With advances in the enabling technologies allowing for the design of ever more believable context-relevant "structural" VR environments (e.g. homes, classrooms, offices, markets, etc.), the next important challenge will involve *populating* these environments with Virtual Human (VH) representations that are capable of fostering believable interaction with *real* VR users. This is not to say that representations of human forms have not usefully appeared in Clinical VR scenarios. In fact, since the mid-1990's, VR applications have routinely employed VHs to serve as stimulus elements to enhance the realism of a virtual world simply by their static presence.

For example, VR exposure therapy applications have targeted simple phobias such as fear of public speaking and social phobia using virtual contexts inhabited by "still-life" graphics-based characters or 2D photographic sprites (Anderson et al., 2005; Pertaub et al., 2002; Klinger, 2005). By simply adjusting the number and location of these VH representations, the intensity of these anxiety-provoking VR contexts could be systematically manipulated with the aim to gradually habituate phobic patients and improve their functioning in the real world. Other clinical applications have also used animated graphic VHs as stimulus entities to support and train social and safety skills in persons with high functioning autism (Rutten et al., 2003; Padgett et al., 2006) and as distracter stimuli for attention assessments conducted in a virtual classroom (Parsons et al., 2007; Rizzo et al., 2006). Additionally, VHs have been used effectively for the conduct of social psychology experiments, essentially replicating and extending findings from studies with real humans on social influence, conformity, racial bias and social proxemics conducted (Blascovich et al., 2002; Bailenson & Beall, 2006; McCall et al., 2009). In an effort to further increase the pictoral realism of such VHs, *Virtually Better Inc.*, began incorporating whole video clips of crowds into graphic VR fear of public speaking scenarios (VBI, 2010). They later advanced the technique by using blue screen captured video sprites of individual humans inserted into graphics-based VR social settings for creating social phobia, public speaking and cue exposure substance abuse treatment and research applications. The sprites were drawn from a large library of blue-screen captured videos of actors behaving or speaking with varying degrees of provocation. These video sprites could then be strategically inserted into the scenario with the aim to modulate the emotional state of the patient by fostering encounters with these 2D video VH representations.

The continued quest for even more realistic simulated human interaction contexts led other researchers to the use of panoramic video capture (Macedonio et al., 2007; Rizzo et al., 2003) of a real world office space inhabited by hostile co-workers and supervisors to produce VR scenarios for anger management research. With this approach, the VR scenarios were created using a 360-degree panoramic camera that was placed in the position of a worker at a desk and then actors walked into the workspace, addressed the camera (as if it was the targeted user at work) and proceeded to verbally threaten and abuse the camera, vis-à-vis, the worker. Within such photorealistic scenarios, VH video stimuli could deliver intense emotional expressions and challenges with the aim of the research being to determine if this method would produce emotional reactions in test participants and if it could engage anger management patients to role-play a more appropriate set of coping responses.

However, working with such fixed video content to foster this form of *faux* interaction or exposure has significant limitations. For example, it requires the capture of a large catalog of possible verbal and behavioral clips that can be tactically presented to the user to meet the requirements of a given therapeutic approach. As well, this fixed content cannot be readily updated in a dynamic fashion to meet the challenge of creating credible real time interactions with a virtual human, with the exception of only very constrained social interactions. This process can only work for clinical applications where the only requirement is for the VH character to deliver an open-ended statement or question that the user can react to, but is lacking in any truly fluid and believable interchange following a response by the user. Consequently, the absence of dynamic interaction with these virtual representations without a live person behind the "screen" actuating new clips in response the user's behavior is a significant limiting factor for this approach. This has led some researchers to consider the use of artificially intelligent VH agents as entities for simulating human-to-human interaction in virtual worlds.

©2010 ICDVRAT; ISBN 978 07049 15022

Clinical interest in artificially intelligent agents designed for interaction with humans can trace its roots to the work of MIT AI researcher, Joe Weizenbaum. In 1966, he wrote a language analysis program called ELIZA that was designed to imitate a Rogerian therapist. The system allowed a computer user to interact with a virtual therapist by typing simple sentence responses to the computerized therapist's questions. Weizenbaum reasoned that simulating a non-directional psychotherapist was one of the easiest ways of simulating human verbal interactions and it was a compelling simulation that worked well on teletype computers (and is even instantiated on the internet today; *http://www-ai.ijs.si/eliza-cgi-bin/eliza_script*). In spite of the fact that the illusion of Eliza's intelligence soon disappears due to its inability to handle complexity or nuance, Weizenbaum was reportedly shocked upon learning how seriously people took the ELIZA program (Howell & Muller, 2000). And this led him to conclude that it would be immoral to substitute a computer for human functions that "...involves interpersonal respect, understanding, and love." (Weizenbaum, 1976).

More recently, seminal research and development has appeared in the creation of highly interactive, artificially intelligent (AI) and natural language capable virtual human agents. No longer at the level of a prop to add context or minimal faux interaction in a virtual world, these VH agents are designed to perceive and act in a 3D virtual world, engage in face-to-face spoken dialogues with real users (and other VHs) and in some cases, they are capable of exhibiting human-like emotional reactions. Previous classic work on virtual humans in the computer graphics community focused on perception and action in 3D worlds, but largely ignored dialogue and emotions. This has now changed. Artificially intelligent VH agents can now be created that control computer generated bodies and can interact with users through speech and gesture in virtual environments (Gratch et al., 2002). Advanced virtual humans can engage in rich conversations (Traum, et al., 2008), recognize nonverbal cues (Morency et al., 2008), reason about social and emotional factors (Gratch & Marsella, 2004) and synthesize human communication and nonverbal expressions (Thiebaux et al., 2008). Such fully embodied conversational characters have been around since the early 90's (Bickmore & Cassell, 2005) and there has been much work on full systems to be used for training (Evans et al., 1989; Kenny et al., 2007; Kenny et al., 2007; Rickel et al., 2001), intelligent kiosks (McCauley & D'Mello, 2006), virtual receptionists (Babu et al., 2006) and virtual patients for clinical training (Kenny et al., 2008; Rizzo, et al., in press). Both in appearance and behavior, VHs have now evolved to the point where they are usable tools for a variety of clinical and research applications.

What follows in this paper is an overview of the *SimCoach* project that aims to develop virtual human support agents to serve as online guides for promoting access to psychological healthcare information and for assisting military personnel and family members in breaking down barriers to initiating the healthcare process. While we believe that the use of virtual humans to serve the role of virtual therapists is still fraught with both technical and ethical concerns, the SimCoach project does not aim to become a "doc in box". Rather, the SimCoach experience is being designed to attract and engage military Service Members (SMs), Veterans and their significant others who might not otherwise seek help. It aims to create an experience that will motivate users to take the first step – to empower themselves to seek information and advice with regard to their healthcare (e.g., psychological health, traumatic brain injury, addiction, etc.) and general personal welfare (i.e., other non-medical stressors such as economic or relationship issues) – and encourage them to take the next step towards seeking more formal resources that are available, when the need is determined.

2. CHALLENGES FOR BREAKING DOWN BARRIERS TO CARE IN MILITARY POPULATIONS AND VETERANS

Research suggests that there is an urgent need to reduce the stigma of seeking mental health treatment in SM and Veteran populations. One of the more foreboding findings in an early report by Hoge et al. (2004), was the observation that among Iraq/Afghanistan War veterans, "…those whose responses were positive for a mental disorder, only 23 to 40 percent sought mental health care. Those whose responses were positive for a mental disorder were twice as likely as those whose responses were negative to report concern about possible stigmatization and other barriers to seeking mental health care." (p. 13). While US military training methodology has better prepared soldiers for combat in recent years, such hesitancy to seek treatment for difficulties that emerge upon return from combat, especially by those who may need it most, suggests an area of military mental healthcare that is in need of attention.

Moreover, the dissemination of healthcare information to military SMs, Veterans and their significant others is a persistent and growing challenge. Although medical information is increasingly available over the web, users can find the process of accessing it to be overwhelming, contradictory and impersonal. At the same time, the need for military-specific health information is growing at an astounding rate. Recent statistics indicate that a growing percentage of military personnel are surviving wounds and injuries received in

©2010 ICDVRAT; ISBN 978 07049 15022

OIF/OEF compared to the conflicts of the past. For example, one report suggests that of all those wounded in Iraq, Afghanistan and nearby staging locations – there is a ratio of 16 wounded servicemen for every fatality. This compares with the Vietnam and Korean wars where there were 2.6 and 2.8 injuries per fatality, respectively, and WWs I and II, which had fewer than 2 wounded servicemen per death (Bilmes, 2007). Advances in training, tactics, body/vehicle armor technology and military battlefield medicine have led to this unprecedented number of survivors of severe battlefield trauma. However, along with these successes in force protection and survivability have come significant challenges in the form of providing health care for these survivors of trauma. In this regard, the reports over the last few years of a surge in U.S. Army suicide rates have again thrust the challenges of military mental health care into the public spotlight. With annual suicide rates steadily rising since 2004, the month of January, 2009 saw 24 suspected suicides, compared to five in January of 2008, six in January of 2007 and 10 in January of 2006 (Jelinek & Hefling, 2009).

In spite of a Herculean effort on the part of the U.S. Department of Defense (DOD) to produce and disseminate behavioral health programs for military personnel and their families, the complexity of the issues involved continue to challenge the best efforts of military mental health care experts, administrators and providers. Since 2004, numerous blue ribbon panels of experts have attempted to assess the current DOD and Veterans Affairs (VA) healthcare delivery system and provide recommendations for improvement (DOD Mental Health Task Force (DOD, 2007), National Academies of Science Institute of Medicine (IOM, 2007), Dole-Shalala Commission Report (Dole et al., 2007), the Rand Report (Tanielian et al., 2008), American Psychological Association (APA, 2007). Most of these reports cite two major areas in need of improvement:

1) Support for randomized controlled trials that test the efficacy of treatment methodologies, leading to wider dissemination of evidenced based approaches

2) Identification and implementation of ways to enhance the healthcare dissemination/delivery system for military personnel and their families in a fashion that provides better awareness and access to care while reducing the stigma of help-seeking.

For example, the American Psychological Association Presidential Task Force on Military Deployment Services for Youth, Families and Service Members (APA, 2007) presented their preliminary report in February of 2007 that poignantly stated that they were, "…not able to find any evidence of a well-coordinated or well-disseminated approach to providing behavioral health care to service members and their families." The APA report also went on to describe three primary barriers to military mental health treatment: *availability, acceptability and accessibility.* More specifically:

1) Well-trained mental health specialists are not in adequate supply (*availability*)

2) The military culture needs to be modified such that mental health services are more *accepted* and less stigmatized,

3) And even if providers were available and seeking treatment was deemed acceptable, appropriate mental health services are often not readily *accessible* due to a variety of factors (e.g. long waiting lists, limited clinic hours, a poor referral process and geographical location).

The overarching goal reported from this and other reports is to provide better awareness and access to existing care while concurrently reducing the complexity and stigma in seeking psychological help. In essence, new methods are needed to reduce such barriers to care.

3. SIMCOACH – AN ONLINE VIRTUAL HUMAN GUIDE FOR PROMOTING ACCESS TO HEALTHCARE INFORMATION AND FOR SUPPORT IN INITIATING LIVE CARE

While advances in technology has begun to show promise for the creation of new and effective clinical assessment and treatment approaches, from Virtual Reality to computerized prosthetics, improvements in the military health care dissemination/delivery system are required to take full advantage of these evolving treatment methodologies, as well as for promoting standard proven intervention options. In response to the clinical health care challenges that the conflicts in Iraq and Afghanistan have placed on the burgeoning population of service members and their families, the U.S. Defense Centers of Excellence for Psychological Health and Traumatic Brain Injury (DCoE) have recently funded our development of an intelligent, interactive, online Virtual Human (VH) healthcare guide program currently referred to as SimCoach. The DCoE's primary mission is to assess, validate, oversee and facilitate sharing of critical information relative to the areas of injury prevention, resilience, identification, treatment, outreach, rehabilitation, and reintegration programs for psychological health and traumatic brain injury. In line with this mission, the SimCoach project is DCoE's first effort to support the development of an online embodied VH presence to serve as a guide for

©2010 ICDVRAT; ISBN 978 07049 15022

assisting Service Members, Veterans and their significant others in their efforts to seek behavioral health information, advice and ultimately, actual care if needed with a clinical provider.

Rather than being a traditional web portal, SimCoach allow users to initiate and engage in a dialog about their healthcare concerns with an interactive VH. Generally, these intelligent graphical characters are being designed to use speech, gesture and emotion to introduce the capabilities of the system, solicit basic anonymous background information about the user's history and clinical/psychosocial concerns, provide advice and support, direct the user to relevant online content and potentially facilitate the process of seeking appropriate care with a live clinical provider. An implicit motive of the SimCoach project is that of supporting users determined to be in need, to make the decision to take the first step toward initiating psychological or medical care with a live provider.

Figure 1. *SimCoach Archetypes – Female Aviator, Battle Buddy, Retired Sergeant Major*

It is not the goal of SimCoach to breakdown all of the barriers to care or to provide diagnostic or therapeutic services that are best delivered by a real clinical provider. Rather, SimCoach will foster comfort and confidence by promoting users' efforts to understand their situations better, to explore available options and initiate treatment when appropriate. Coordinating this experience will be a VH SimCoach, selected by the user from a variety of archetypic character options (See Figure 1), who will answer direct questions and/or guide the user through a sequence of user-specific questions, exercises and assessments. This interaction between the VH and the user will provide the system with the information needed to guide users to the appropriate next step of engagement with the system or to initiate contact with a live provider. Again, the SimCoach project is not conceived to deliver diagnosis or treatment or as a replacement for human providers and experts. Instead, SimCoach will aim to start the process of engaging the user by providing support and encouragement, increasing awareness of their situation and treatment options, and in assisting individuals, who may otherwise be initially uncomfortable talking to a "live" care provider, in their efforts to initiate care.

Users can flexibly interact with this character by typing text, clicking on character generated menu options and have some limited speech interaction during the initial phases of development. The feasibility of providing the option for full spoken natural language dialog interaction on the part of the user will be explored in the later stages of the project. Since this is designed to be a web-based system that will require no downloadable software, it is felt that voice recognition is not at a state where it could be reliably used at the current time. The options for SimCoach appearance, behavior and dialog is being designed to maximize user comfort and satisfaction, but also to facilitate fluid and truthful disclosure of medically relevant information. Focus groups and "Wizard of OZ" user studies are currently in progress in order to prepare the SimCoach interaction system for a wide range of potential dialog.

Based on the issues delineated in the initial interview, the user will be given access to a variety of general relevant information on psychology, neurology, rehabilitation, the military healthcare system, and also to other SMs and Veterans by way of a variety of social networking tools (e.g., 2nd Life, Facebook, etc.). When relevant, users will also be directed (in later SimCoach interations) to experts on specific areas such as stress,

©2010 ICDVRAT; ISBN 978 07049 15022

brain injury, marriage counseling, suicide, rehabilitation, reintegration and other relevant specialties. The user can progress through the system at their own pace over days or even weeks as they feel comfortable and the SimCoach will be capable of "remembering" the information acquired from previous visits and build on that information in similar fashion to that of a growing human relationship. However, the persistence of the SimCoach's memory for previous sessions will require the user to sign into the system with a user name and password, but that is optional for use of the system. Interspersed within the program will be the option to allow the user to perform some simple neurocognitive and psychological testing to inform the SimCoach's creation of a model of the user to enhance the reliability and accuracy of the SimCoach output to the user, to support user self-awareness, and better guide the delivery of initial referral options. Users will also have the option to print out a summary of the computerized sessions to bring with them when seeking clinical care to enhance their comfort level, armed with knowledge, when dealing with the "real" human clinical care providers and experts. We are also creating software authoring tools that will allow other clinical professionals to create SimCoach "content" to enhance the likelihood that the program will evolve based on other care perspectives and emerging needs in the future.

4. SIMCOACH USE-CASE

The following is a use-case of how SimCoach will interact with a potential user.

Maria was the 23-year old wife of Juan, an OIF veteran who had completed two deployments before leaving the service. After his return, she noticed something different. He had become distant, never discussed his experiences in Iraq, and when asked, he would answer, "that was then, this is now, case closed". He also wasn't as involved with their two children (the 2nd one was born while he was in Iraq), only playing with their oldest boy after hours of begging. For the most part, Juan stayed home and had yet begun to look for a civilian job. He didn't sleep much and when he did manage to fall asleep, he would often wake up after an hour, highly agitated claiming that he heard someone trying to get in the bedroom window. When this happened, he would sometimes sit till dawn, peering through slits in the closed blinds, watching for the "imaginary" intruder to return. He seemed jumpy when not drinking and watching TV. He drank heavily during the day and Maria would often find him asleep or passed out on the couch when she got home from her job after picking the kids up from her mother's house. She told her mother that it felt like she was living with a ghost, but that she still loved him. She just wanted the "old Juan" back. However, each day things got worse and she was feeling like she couldn't live like this much more. She felt guilty for the increasing resentment that she felt but didn't know how (or was afraid) to talk to Juan about what she was feeling. Juan also kept a pistol in the house and one time she had moved it off the dresser while cleaning and when Juan couldn't find it, he went ballistic and ran frantically around the house, screaming, "how am I gonna protect my family without my weapon!"

Maria was at a loss as to what to do when her mother mentioned hearing on Oprah about a way to find help for these kinds of problems on the internet with a thing called "SimCoach". Maria had only occasionally "played" on the AOL games site before and she didn't own a computer, but her older sister's son was a "computer nut" and agreed to let her come over to use his computer and try out SimCoach. She couldn't understand how a computer could help her, but she was desperate for any help she could get. So her nephew showed her how to type in the address for www.simcoach.mil on his computer and then went out with his friends to a movie.

Maria was intrigued when the screen lit up and created the illusion of standing in front of a "craftsman"-like building with the sign above it reading, "DCoE Helpcenter". Immediately the "virtual" director of the center walked out onto the porch and beckoned her to come in. The director stated that "we are here to understand your needs and get you started on the path to help" and showed Maria a poster just inside the door that had images and short biographies of the staff. Pointing towards the poster, she said, "here is our staff, have a look and click on the picture of who you think you would feel comfortable meeting with." Maria paused when she noticed a staff member that reminded her of a teacher she had in high school who was always helpful and kind to her. She clicked on this picture and was then guided through the hallway of the center that actually looked quite warm and peaceful with virtual people in the hall smiling and talking to each other softly. The program whisked her into a room where Dr. Hartkis, sitting in a thick fabric chair next to a fireplace, smiled, and softly asked her how he could help. Maria knew that this was just a virtual human, but for some reason she felt comforted by his soft voice and kind facial expressions. She had never been to a clinician before for this kind of help and was surprised by how safe and comfortable she felt. Not knowing what to expect, she described how her husband, Juan, was having problems ever since he came back from the war. She was surprised when the doctor said in a reassuring voice, "If you want

©2010 ICDVRAT; ISBN 978 07049 15022

to tell me more about it, I think I can help you and your family." After requesting some basic information, Dr. Hartkis then asked Maria some questions that seemed like he really might "understand" some of what she was going through. Eventually, after answering a series of thoughtful questions, Dr. Hartkis reassuringly smiled and then pointed to a wall in the room and said, "Here are some websites that have information that is available to help folks that are going through what you are feeling. We can pull up one of them and take a look at what is available or I can find a care provider in or near your zip code that we can make an appointment with right now so you can begin to find the help that both you and Juan could benefit from. Or, if you're not ready for that yet, we can still talk more about what you're going through now."

Maria couldn't believe that this computer character seemed so genuine in his face and his manner, and that she felt like she wanted to tell him more. Perhaps he might really be able to get her started on the road to help both her and Juan? Suddenly she realized that she had been online for an hour and needed to go home. As she was leaving, she wondered aloud if she could think about the options that she learned about today and then come back to make a decision on what to do. Dr. Hartkis smiled and said, "Of course we can meet again…you see, I will always be here to guide you to the help you need, whenever you're ready."

5. INTERACTION STRATEGY

While the use-case presented above is fictional, it illustrates one of a myriad of forms of confidential interaction that a tireless and always-available virtual human can foster. A fundamental challenge of the SimCoach project will be to better understand the diverse needs of the user base such that appropriate individual user experiences can be delivered to promote better healthcare access. At the most basic level, there are immense differences in the needs of service members and their families. Further, there are likely large differences in the level of awareness that users will have of existing resources and in their own need/desire to engage such resources. Within the service member population there is a high likelihood that individual users will have had very diverse combat experiences, help-seeking histories and consequent impact on significant others. The net result of attempting to engage such a diverse user base is that the system will need to be able to employ a variety of general strategies and tactics to be relevant to each individual user.

In this regard, the SimCoach project is employing a variety of techniques to create the user experience. One relevant clinical model is the PLISSIT clinical framework (**P**ermission, **L**imited **I**nformation, **S**pecific **S**uggestions, and **I**ntensive **T**herapy) (Annon, 1976), which provides an established model for encouraging help-seeking behaviors in persons who may feel stigma and insecurity regarding a clinical condition. In the SimCoach project, the aim is to address the "PLISS" components, leaving the intensive therapy component to live professionals to which users in need of this level of care can be referred. Another source of knowledge is social work practice. Such models take a case management approach, serving both as an advocate and a guide. The SimCoach development team is also leveraging knowledge from the entertainment/gaming industry. While knowledge from this community is not typically applied towards healthcare, a primary aim by this community is in the explicit attraction and engagement of individuals' attention. As we work to develop this web-based VH interactive system we are working closely with experts in all three of these models to achieve our goal of engaging and focusing this unique user base on the steps to initiate care as needed. Additionally, all interactions will be consistent with findings that suggest that interventions with individuals with PTSD and other psychosocial difficulties achieve the following: 1) promotion of perceptions of self-efficacy and control 2) encouragement of the acceptance of change; 3) encouragement of positive appraisals; and 4) an increase in the usage of adaptive coping strategies (Whealin et al., 2008). These principles of intervention will be implicit in all of the interactions between the SimCoach and its users.

6. CONCLUSIONS

The systematic use of artificially intelligent virtual humans in Clinical Virtual Reality applications is still clearly in its infancy. But the days of limited use of VH's as simple props or static elements to add realism or context to a VR application are clearly in the past. In this paper we have presented our general approach to the design and development of the SimCoach VH project envisioned to serve as an online clinical healthcare guide or coach. This work is focused on breaking down barriers to care (stigma, unawareness, complexity, etc.) by providing military SMs, Veterans, and their significant others with confidential help in exploring and accessing healthcare content and for promoting the initiation of care with a live provider if needed. This work will also afford many research opportunities for investigating the functional and ethical issues involved in the process of creating and interacting with virtual humans in a clinical context. While the ethical challenges may

©2010 ICDVRAT; ISBN 978 07049 15022

be more intuitively appreciated, the functional technology challenges are also significant. However, although this project represents an early effort in this area, it is our view that the clinical aims selected can still be usefully addressed in spite of the current limits of the technology. As advances in computing power, graphics and animation, artificial intelligence, speech recognition, and natural language processing continue to develop at current rates, the creation of highly interactive, intelligent VHs for such clinical purposes is not only possible, but probable.

7. REFERENCES

American Psychological Association Presidential Task Force on Military Deployment Services for Youth, Families and Service Members. (2007). The Psychological Needs of U.S. Military Service Members and Their Families: A Preliminary Report. Retrieved 04/18/2007, from: *http://www.apa.org/releases/MilitaryDeploymentTaskForceReport.pdf*

P L Anderson, E Zimand, L F Hodges and B O Rothbaum (2005), Cognitive behavioral therapy for public-speaking anxiety using virtual reality for exposure, *Depression and Anxiety*. **22,** *3*, pp. 156-158.

J Annon (1976), *Behavioral Treatment of Sexual Problems*. Harper-Collins. NY, NY.

S Babu, S Schmugge, T Barnes, L Hodges (2006), What Would You Like to Talk About? An Evaluation of Social Conversations with a Virtual Receptionist. In *IVA 2006*, (J Gratch et al., Eds.), Springer-Verlag, Berlin, Germany, pp. 169-180.

J N Bailenson and A C Beall (2006), Transformed social interaction: Exploring the digital plasticity of avatars, In *Avatars at Work and Play: Collaboration and Interaction in Shared Virtual Environments* (R Schroeder and A Axelsson, Eds), Springer-Verlag, Berlin, Germany, pp. 1-16.

T Bickmore and J Cassell (2005), Social Dialogue with Embodied Conversational Agents. In *Advances in Natural, Multimodal Dialogue Systems* (J van Kuppevelt, L Dybkjaer and N Bernsen, Eds.), Kluwer Academic, New York.

L Bilmes (2007), Soldiers Returning from Iraq and Afghanistan: The Long-term Costs of Providing Veterans Medical Care and Disability Benefits, Faculty Research Working Paper Series, John F. Kennedy School of Government - Harvard University, Downloaded on 1/20/2007 at: *http://ksgnotes1.harvard.edu/Research/wpaper.nsf/rwp/RWP07-001*

J Blascovich, J Loomis, A Beall, K Swinth, C Hoyt and J Bailenson (2002), Immersive virtual environment technology: Not just another research tool for social psychology, *Psychological Inquiry*, 13, pp. 103-124.

DOD Mental Health Task Force Report (2007), Downloaded on 6/15/2007 at: *http://www.health.mil/dhb/mhtf/MHTF-Report-Final.pdf*

Dole-Shalala Commission (2007), Serve, Support, Simplify: Report of the President's Commission on Care for America's Returning Wounded Warriors.

D Evans, M Hern, M Uhlemann and A Lvey (1989), *Essential Interviewing: A Programmed Approach to Effective Communication,* (3rd Ed), Brooks/Cole Publishing Company.

J Gratch, et al. (2002), Creating Interactive Virtual Humans: Some Assembly Required, *IEEE Intelligent Systems*, July/August, pp. 54-61.

J Gratch, and S. Marsella (2004), A domain independent framework for modeling emotion, *Journal of Cognitive Systems Research*. **5,** *4*, pp. 269-306.

M K Holden (2005), Virtual Environments for Motor Rehabilitation: Review, *CyberPsych. and Behav.*, **8**, *3*, pp. 187-211.

S R Howell and R. Muller (2000), Website found at: *http://www.psychology.mcmaster.ca/beckerlab/showell/ComputerTherapy.PDF*

Institute of Medicine of the Academies of Science (2007), Treatment of PTSD: An Assessment of the Evidence, Downloaded on 10/18/2007 at: *http://www.nap.edu/catalog.php?record_id=11955#toc*

P Jelinek and K Hefling (2009), AP Report: Army suicides at record high, passing civilians, Downloaded on 1/29/2009 at: *http://www.google.com/hostednews/ap/article/ALeqM5jrRijfpxg8ZdUbcDpGbmnEpYPH9wD9616BB80*

P Kenny, A Hartholt, J Gratch, W Swartout, D Traum, et al. (2007), Building Interactive Virtual Humans for Training Environments, *Proceedings of the I/ITSEC.*

P Kenny, T Parsons, G Reger, C Pataki and A A Rizzo (2008), Virtual Patients for Future Leaders, *The Proceedings of the 2008 Interservice/Industry Training, Simulation & Education Conference*, Dec. 1-4, 2008, Orlando, FL.

©2010 ICDVRAT; ISBN 978 07049 15022

E Klinger (2005), Virtual Reality Therapy for Social Phobia: its Efficacy through a Control Study. Paper presented at *Cybertherapy 2005*, Basal, Switzerland.

M F Macedonio, T Parsons, B Wiederhold and A A Rizzo (2007), Immersiveness and Physiological Arousal within Panoramic Video-based Virtual Reality. *CyberPsychology and Behavior*. **10**, *4*, 508-515.

C McCall, J Blascovich, A Young, S Persky (2009), Proxemic behaviors as predictors of aggression towards Black (but not White) males in an immersive virtual environment, *Social Influence*, pp. 1-17.

Virtually Better Homepage. Website found at: *www.virtuallybetter.com*

L McCauley and S D'Mello (2006), A Speech Enabled Intelligent Kiosk, In *IVA 2006* (J. Gratch et al. Eds), Springer-Verlag, Berlin, Germany, pp. 132-144.

L P Morency, I de Kok et al. (2008), Context-based Recognition during Human Interactions: Automatic Feature Selection and Encoding Dictionary, *10th International Conference on Multimodal Interfaces*, Chania, Greece, IEEE.

L Padgett, D Strickland, C Coles (2006), Case study: Using a virtual reality computer game to teach fire safety skills to children diagnosed with Fetal Alcohol Syndrome (FAS), *Journal of Pediatric Psychology*, **31**, *1*, pp. 65-70.

T Parsons, T Bowerly, J G Buckwalter and A A Rizzo (2007), A controlled clinical comparison of attention performance in children with ADHD in a virtual reality classroom compared to standard neuropsychological methods, *Child Neuropsychology*, **13**, pp. 363-381.

T Parsons and Rizzo, A A (2008), Affective Outcomes of Virtual Reality Exposure Therapy for Anxiety and Specific Phobias: A Meta-Analysis, *Journal of Behavior Therapy & Experimental Psychiatry*, **39**, pp. 250-261.

D-P Pertaub, M Slater and C Barker (2002), An Experiment on Public Speaking Anxiety in Response to Three Different Types of Virtual Audience. *Presence*, **11** ,*1*, pp. 68-78.

M Powers and P M G Emmelkamp (2008), Virtual reality exposure therapy for anxiety disorders: A meta-analysis, *Journal of Anxiety Disorders*, **22**, pp. 561-569.

H Prendinger and M Ishizuka (2004), *Life-Like Characters – Tools, Affective Functions, and Applications*, Springer-Verlag, Berlin, Germany.

J Rickel, J Gratch, R Hill, S Marsella and W Swartout (2001), Steve Goes to Bosnia: Towards a New Generation of Virtual Humans for Interactive Experiences. *The Proceedings of the AAAI Spring Symposium on AI and Interactive Entertainment*, Stanford University, CA.

A A Rizzo, K Ghahremani, L Pryor and S Gardner (2003), Immersive 360-Degree Panoramic Video Environments. In *Human-Computer Interaction: Theory and Practice* (J Jacko and C Stephanidis, Eds.), L.A. Erlbaum, New York, **1**, pp. 1233-1237.

A A Rizzo, D Klimchuk, R Mitura, T Bowerly, J G Buckwalter and T Parsons (2006), A Virtual Reality Scenario for All Seasons: The Virtual Classroom, *CNS Spectrums*, ***11,*** *1*, pp. 35-44.

G Riva (2005), Virtual Reality in Psychotherapy: Review, *CyberPsychology and Behavior*, **8** ,*3*, pp. 220-230.

F D Rose, B M Brooks and A A Rizzo (2005), Virtual Reality in Brain Damage Rehabilitation: Review. *CyberPsych. and Behavior*, **8,** *3*, pp. 241-262.

A Rutten, S Cobb, H Neale, S Kerr, A Leonard, S Parsons and P Mitchell (2003), The AS interactive project: single-user and collaborative virtual environments for people with high-functioning autistic spectrum disorders, *Journal of Visualization and Computer Animation*, **14**, *5*, pp. 233-241.

D Traum, J Gratch, et al. (2008), Multi-party, Multi-issue, Multi-strategy Negotiation for Multi-modal Virtual Agents, *8th International Conference on Intelligent Virtual Agents*, Springer, Tokyo, Japan.

T Tanielian, L H Jaycox, T L Schell, G N Marshall, M A Burnam, C Eibner, B R Karney, L S Meredith, J S Ringel, et al. (2008), Invisible Wounds of War: Summary and Recommendations for Addressing Psychological and Cognitive Injuries, *Rand Report* Retrieved 04/18/2008, from: *http://veterans.rand.org/*

M Thiebaux, A Marshall, et al. (2008), SmartBody: Behavior Realization for Embodied Conversational Agents. *International Conference on Autonomous Agents and Multi-Agent Systems*. Porto Portugal.

J Weizenbaum (1976), *Computer Power and Human Reason*, W H Freeman, San Francisco.

J M Whealin, J I Ruzek and S Southwich (2008), Cognitive-behavioral theory and preparations for professionals at risk for trauma exposure, *Trauma Violence Abuse*, **9**, pp. 100-113.

©2010 ICDVRAT; ISBN 978 07049 15022

Development of an interactive stepping game to reduce falls in the elderly

B S Lange[1], S M Flynn[1], C Y Chang[1], W Liang[2], C L Chieng[2], Y Si[2], C Nanavati[2], A A Rizzo[1]

[1]Institute for Creative Technologies, University of Southern California, 12015 Waterfront Dr, Playa Del Rey, CA, USA

[2]Viterbi School of Engineering, University of Southern California, 3650 McClintock Ave, Los Angeles, USA

lange@ict.usc.edu, sherylflynn@yahoo.com, kchang@ict.usc.edu, arizzo@usc.edu

[1]www.ict.usc.edu, [2]www.viterbi.usc.edu

ABSTRACT

More than one-third of people over the age of 65 experience falls each year, and those who fall once are two to three times more likely to fall again. A fall can significantly limit a person's ability to remain self-sufficient. Fall injuries are responsible for significant disability, reduced physical function, and loss of independence. However, falls are not an inevitable result of aging. Systematic reviews of fall intervention studies have established that prevention programs can reduce falls. Physical activities, including strengthening exercises, tai chi, dancing and walking have been demonstrated to improve balance and decrease risk of falls in older adults. Modified dance-based exercises that include step-based movements have been demonstrated to improve endurance and balance in older adults. Dance video games, using a dance mat with areas that the player must step on in time with cues on the screen, have been demonstrated to improve activity and mood and reduce weight in children and youth. However, these dance games often include fast paced music, frequent jumping and an overload of visual information, movement and colors on the screen. This paper outlines the development of a prototype rhythm game that leverages the benefits of step-based exercise and dance video games to improve balance and reduce falls in older adults.

1. INTRODUCTION

Balance is the ability to maintain the body's center of gravity (COG) over the base of support (BOS) and requires full integrity of an elegant and complicated biological system. Balance can be described as being either static (maintaining postural stability while standing quiet) or dynamic (maintaining postural control during voluntary movement) (Shumway-Cook and Woolacott 2007). Postural control is the ability to maintain an upright position (in sitting or standing) when stationary or performing activities. The postural control system incorporates 1) sensory detection (through the visual, vestibular, auditory, kinesthetic and somatosensory systems), 2) integration of sensorimotor information within the central nervous system and comparison with external environment and, 3) proper coordinated movement patterns and responses (Shumway-Cooke and Woolacott 2007).

Balance relies on the visual, somatosensory and vestibular sensory systems. When damage occurs to one or more of these systems, balance impairment will result. An inability to correctly maintain COG over the BOS results in impaired balance. More specifically, loss of the ability to accurately assess (or sense) the position of the COG relative to the BOS will disrupt balance. When automatic movements to maintain balance are triggered too slowly or ineffectively, balance will become distorted.

Impairments impacting balance, such as muscular weakness, proprioceptive deficits, limitations in range of motion and visual/vestibular deficits, can lead to falls and restrict an individual's normal motor activities, limiting independence and affecting quality of life (Laughton et al., 2003). Changes associated with aging include a decrease in visual acuity, hearing, muscle strength, coordination and reflexes. These changes can make older adults more likely to fall. More than one-third of people over the age of 65 experience falls each year, and those who fall once are two to three times more likely to fall again. A fall can significantly limit a person's ability to remain self-sufficient. Fall injuries are responsible for significant disability, reduced

©2010 ICDVRAT; ISBN 978 07049 15022

physical function, and loss of independence. However, falls are not an inevitable result of aging. Systematic reviews of fall intervention studies have established that prevention programs can reduce falls (Sherington et al., 2008).

Physical activities, including strengthening exercises, Tai Chi, dancing and walking have been demonstrated to improve balance and decrease risk of falls in older adults. Dancing is a fun, physical and an expressive activity open for participation by people with all levels of coordination. Modified dance-based exercises that include step-based movements have been demonstrated to improve endurance and balance in older adults (Hopkins et al., 1990; Shigematsu et al., 2002; Hui et al., 2008). Dance involving stepping in time to a beat can improve and maintain strength, balance and coordination. Dancing can also increase body awareness, kinesthetic awareness, challenge attention and improve self-esteem and confidence (Hopkins et al., 1990; Shigematsu et al., 2002; Hui et al., 2008).

Dance video games, using a dance mat with areas that the player must step on in time with cues on the screen, have been demonstrated to improve activity and mood and reduce weight in children and youth (Unnithan et al., 2005; Tan et al., 2002; Hindery 2005). These dance games often include fast paced music, a frequent jumping and an overload of visual information, movement and colors on the screen and have not been tested in elderly populations. Furthermore, the use of a dance-pad limits the amount and versatility of the stepping pattern.

The objective of this study was to develop low-cost camera tracking technology for multiple limbs in order to develop a step-based rhythm game that caters specifically to adults over the age of 65 years.

2. METHODS

2.1 Existing Technology

A number of step-based games are currently available for commercial video game consoles. The objective of Dance Dance Revolution style games, available on the Nintendo® Wii™, Microsoft® Xbox and PlayStation®(PS2 and PS3) platforms, is to either tap or step on a sensor located on a soft mat/pad or platform under the player's feet (Figure 1). Points are scored if the player taps or steps on the sensor at precisely the right time and in time with the music. The cues on the screen indicate the direction in which the player is required to move their feet in order to score points. The player must step on the corresponding sensor as the moving cue arrow on the screen overlaps the stationary target arrow (Figure 1). The levels range from 1 – 10; the most difficult levels have increasingly fast moving arrows. Dance Dance Revolution style games are fast paced and require speed (often over 110bpm), coincident timing, attention and intact balance. However, even at the lowest game level, the movements are likely to be difficult for some older adults to complete successfully and safely. The background and graphics can be distracting and there is limited ability for alteration in speed, music style, and visual stimuli.

a) b)

Figure 1. *a) Dance Dance Revolution (DDR) dance pad, b) Screenshot of DDR SuperNova game.*

The Hasbro U-dance™ has taken dance games away from the standard mat format and introduced the ability to play a step-based game without being limited to the dance mat. Hasbro released this free style dancing game in 2008. It is not a traditional console game; the infrared camera tracking system plugs directly into the TV. With reflectors attached to their shoes, the player sees a representation of their feet on the screen. The goal of the player is to move their foot so that the representation of their foot moves to the corresponding area on the screen where a target foot is located. Whilst providing more freedom for step-based training, the U-dance™ has a limited choice of songs, contains a large amount of jumping movements, and provides negative feedback if the player is not performing well.

©2010 ICDVRAT; ISBN 978 07049 15022

Figure 2. Udance™ *system (www.u-dance-game.com).*

Although commercially available options exist for step-based training, the games do not cater to varying levels of ability. The use of commercially available games for physical/balance training could provide participants with a negative experience in which the tasks they are required to perform are too difficult, potentially reducing motivation and self-confidence.

Researchers have begun to explore the use of modified Dance games for older adults in which the key aspects of balance training can be controlled and measured. Smith et al. (2009) developed a modified version of Dance Dance Revolution, using a dance pad and computer based interaction programmed in MatLab. A series of studies was performed in older adults over the age of 70 years. During the simple step task, drift speed and step rate of visual cues were modified. The results of the study confirmed that performance errors (poorly timed steps, incorrect targets) increased with an increase in speed and step rate. Optimal step rate for the sample was found to be one step every two seconds.

Touchtown's Dancetown Fitness system® incorporates assessment tools (Senior Fitness test, Timed Up and Go, Tinetti Balance and Gait Test and Six-Minute Walk Test), slower dance step movements and age-appropriate music for training older adults using a Dance Dance Revolution dance pad system. However, no published literature exists supporting the effectiveness of the system to assess and train balance in older adults.

2.2 System Development

The objective of this study was to develop low-cost camera tracking technology for multiple limbs in order to develop a step-based rhythm game that caters specifically to adults over the age of 65 years. The use of a dance pad can limit weight-shift from limb to limb, encouraging a step and tap task to be performed. A functionally realistic step pattern is rarely performed when using a dance pad. Therefore, this computer based activity interfaces with camera tracking equipment that sends real time information about the player's foot movements to the game. The system consists of a PC, two Logitech web cameras and two different colored LED devices (Figure 3). The LED devices have been designed to attach to the right and left shoe of the user with an adjustable band (Figure 4). The system incorporates an algorithm of feature point based motion tracking using two web cameras. The algorithm was developed to track two LED objects independent of one another in real-time 3D space. The steps involved in this process were to correctly indentify the feature points in an image sequence, find the trajectories of these points and model the tracking result and use epipolar geometry to construct these points in 3D environment.

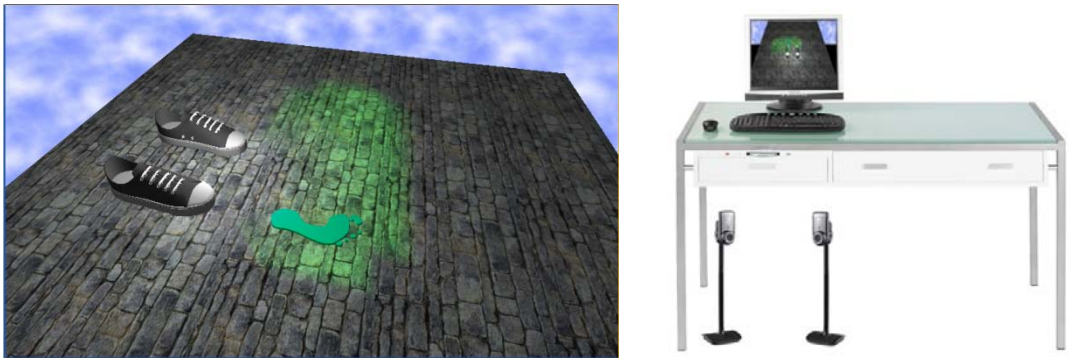


Figure 3. *a) Screen shot of game prototype, b) Set up of screen and cameras.*

©2010 ICDVRAT; ISBN 978 07049 15022

Figure 4. *LED devices attached to right and left shoes of the user (tracked by web cameras).*

The game-based interaction was developed using Microsoft Visual Studio 2008 and Ogre3D, an open source gaming engine. At this early prototype stage, the goal of the game is for the player to control two shoes on the screen. The player is given cues on the screen to move the left and right shoe toward green and orange targets respectively. The resulting interaction involves the player using their own foot movement to control the shoes on the screen in time to a steady beat. The user must follow a set of color-coded footprints on the screen. When the target footprint is captured a sound effect is generated to provide extrinsic knowledge of performance to the player.

A key aspect of the development of this interaction is the gameplay options menu, in which players can adjust the speed, target pattern and difficulty level. The user has the option to change the speed of the stimuli, the step length, the color of the shoes, the pattern of movement and the background, allowing the game prototype to be individualized for the user. The available backgrounds range from a simple grey background, to more complicated brick patterns and a distracting flashing light pattern (figure 5). The features within the footprint pattern that can be controlled are the direction where the footprint will move to (left, right, up, down, diagonal), speed of cues and step length. The footstep sequence for the user, including step length and moving pattern can be calculated via a look-up table. Figure 6 demonstrates examples of possible step patterns.

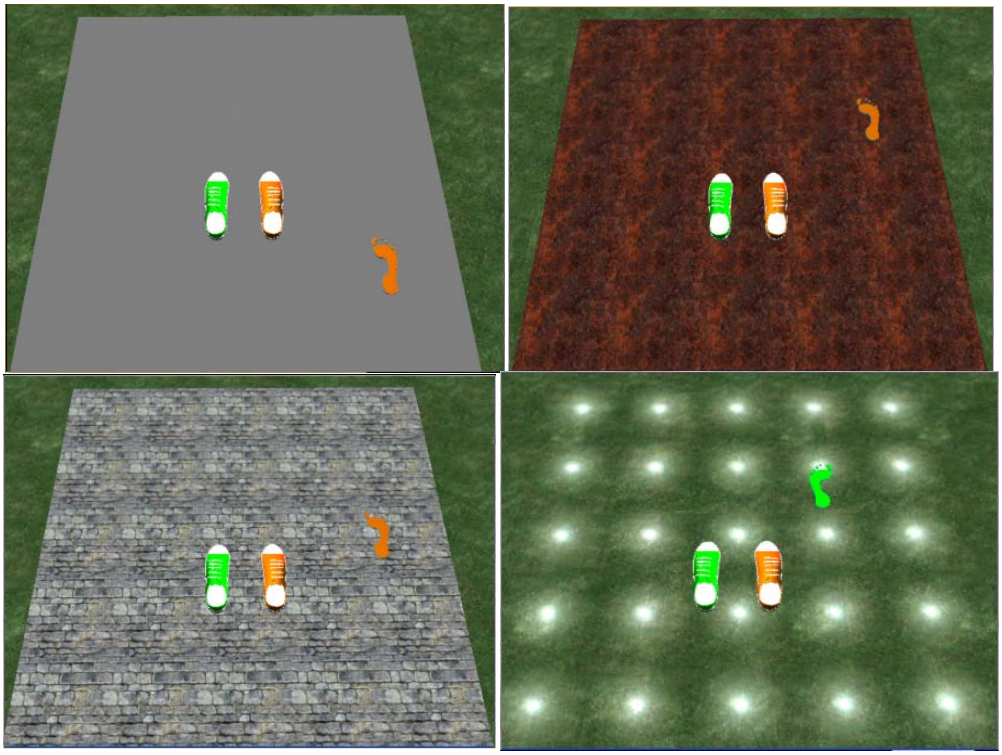


Figure 5. *Background options for game prototype: simple grey, brick pattern, rusty pattern, flashing light pattern.*

©2010 ICDVRAT; ISBN 978 07049 15022

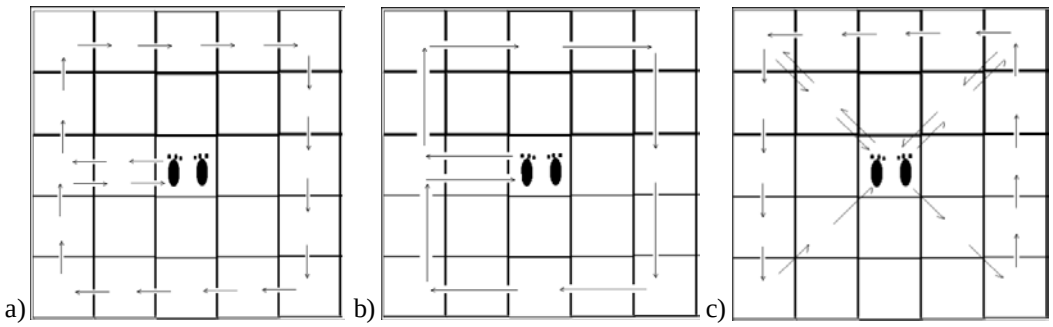


Figure 6. *Possible step patterns calculated using the look-up table. Patterns can be set before starting the game. a) Footprint pattern move around a full circle with 1 unit length for each step (total steps of both left and right feet is 42); b) Footprint pattern moves around a full circle with 2 unit length for each step (total steps = 22); c) More complex footprint pattern with diagonal directions (total steps = 50).*

3. RESULTS

3.1 Initial Assessment of System

3.1.1 Procedure. The prototype system underwent preliminary usability assessment with a sample of three physical therapists and four young healthy participants (aged 16-43 years). Four of the seven participants had previous experience of playing Dance Dance Revolution. Each of the participants were asked to attach the LED devices to the left and right feet, stand in front of the camera (a one camera system was tested in this initial assessment) and follow the instructions on the screen. The participants were asked to comment on their experience through a semi-structured interview consisting of open-ended questions. The researchers also manually recorded observations of the interaction. All participants were able to attach the LED devices to their shoes, without assistance and performed the interaction following a short learning period. Participants experienced slow (0.5 step/sec), moderate (1 step/sec) and fast (2 steps per second) cue rate, all four background options and performed two different movement patterns.

3.1.2 Outcomes. All participants reported enjoying the experience. For two therapists and one adult participant, the devices became unattached during the interaction. The strap was easily repositioned. Physical Therapists supported the further development of this system for use as a balance-training tool. Two therapists indicated that the step length was not large enough and requested a larger step length option. One therapist suggested that an outline of possible step patterns be added to the lookup table for a wider variety of movements. Participants offered suggestions for a number of potential improvements to the prototype. First, each of the participants reported the fast cue rate was too fast to follow. When asked to compare this device with Dance Dance Revolution (DDR), the participants described the freedom of foot movement as a benefit of the prototype, however the music and variety of game play in DDR was still more appealing. Some participants provided other timing based themes for gameplay to be considered and brainstormed in more detail by the research team.

The investigators noted many smiles and laughter while interacting with the device and software. In order to increase the step area, the investigators noted during the interactions that camera placement would require a stand that can be altered in height and angle to allow for better range of movement within the interaction space (area covered by the camera view).

3.2 Planned enhancements and improvements

Based upon the suggestions from the participants, further enhancements of the device include a re-design of the LED strap for the shoe, design of a height-adjustable camera stand for optimum and individualized camera placement, enhanced clinician user-interface menu and enhanced step pattern selection look-up table/drop down menu.

4. CONCLUSIONS

Following improvements, this low-cost tracking system and interactive stepping game prototype will be further assessed for usability with a sample of healthy older adults. Iterations of the game will involve improving upon the game content and interaction goals. Differences between this prototype step-based game

©2010 ICDVRAT; ISBN 978 07049 15022

and existing commercially available games include the ability to adjust the gameplay difficulty level to tailor the game for a range of levels of ability. Changes, such as the removal and addition of distractions on the screen, the speed of the interaction, the amount of feedback provided and the pattern of movement required, will provide a flexible system that can cater to users at a variety of levels of ability. The player will be provided with a variety of feedback. First, unlike many off-the-shelf games, the feedback will always be positive and supportive so as to encourage and motivate continued use. Second, the player will be provided with knowledge of performance feedback regarding accuracy of step placement. Lastly, third, upon completion of the game, the player will receive knowledge of results feedback regarding overall-game score/mean accuracy for each foot. Once completed, this low-cost tracking system and interactive stepping game will undergo formal functional outcome assessment of a four week training period with pre/post balance assessments (Timed Up and Go Test, Berg Balance Scale, Single Limb Stance, Romberg Test) in a sample of 15 older adults.

Acknowledgements: The authors would like to thank the therapists and patients at Precision Rehabilitation in Long Beach for their feedback. The authors would also like to thank Scott Berman for the development of the LED device attachments and Joe Yip for artwork. This work was supported in part by NIDRR through the OPTT RERC at the University of Southern California.

5. REFERENCES

R Hindery (2005), Japanese video game helps people stay fit and lose weight. Associated Press Worldstream.

D R Hopkins, B Murruh, W W K Hoeger, R C Rhodes (1990), Effect of low-impact aerobic dance on the functional fitness of elderly women. *Gerontologist*. 30. pp 189-92.

E Hui, B T Chui, J Woo (2008), Effects of dance on physical and psychological well-being in older persons. *Archives of Gerontology and Geriatrics*.

C A Laughton, M Slavin, K Katdare, L Nolan, J F Bean, D C Kerigan, E Philips, L A Lipsitz, J J Collins (2003), Aging, muscle activity, and balance control: Physiologic changes associated with balance impairment. *Gait and Posture*. 18. pp. 101-108.

C Sherrington, J C Whitney, S R Lord, R D Herbert, R G Cumming, J C T Close (2008), Effective exercise for the prevention of falls: A systematic Review and meta-analysis. *JAGS*. 56. pp 2234-2243.

R Shigematsu, M Chang, N Yabushita (2002), Dance-based aerobic exercise may improve indices of falling risk in older women. *Age Ageing*. 31. pp 261-6.

A Shumway-Cook, M H Woolacott (2007), Motor Control: Translating Research into Clinical Practice. Philadelphia: Lippincott Williams and Wilkins.

S T Smith, C Sherrington, S Studenski, D Schoene, S R Lord (2009), A novel Dance Dance Revolution system for in-home training of stepping ability: basic parameters of system use by older adults. *Br J Sports Med.*

B Tan, A R Aziz, K Chua, K C The (2002), Aerobic demands of the dance simulation game. *International Journal of Sports Medicine*. 23. pp 125-129.

V B Unnithan, W Houser, B Fernhall (2005), Evaluation of the energy cost of playing a dance simulation video game in overweight and non-overweight children and adolescents. *International Journal of Sports Medicine*. 26. pp 1-11.

©2010 ICDVRAT; ISBN 978 07049 15022

A virtual reality approach to gait training in service members with lower extremity amputations

S E Kruger

Walter Reed Army Medical Center
Washington, DC, USA

National Intrepid Center of Excellence
Bethesda, MD, USA

sarah.kruger@med.navy.mil

www.wramc.amedd.army.mil, www.dcoe.health.mil/ComponentCenters/NICoE.aspx

ABSTRACT

Gait training is an essential part of the rehabilitation process for those with lower extremity (LE) amputations. For service members at Walter Reed Army Medical Center, the Computer Assisted Rehabilitation Environment (CAREN) allows virtual reality to be incorporated into gait training as an adjunct to conventional therapies. This retrospective case series examines the self-selected velocities achieved in two different virtual environments (VE) by 11 service members with LE amputations. These VEs allowed participants to progress from level walking to more challenging terrain. Over periods of four to eight weeks, all participants were found to increase their self-selected velocities; progression appears to be individual. The preliminary results obtained indicate that further investigation is warranted.

1. INTRODUCTION

As of March 2010, over 960 service members have sustained major limb amputations as a result of injuries incurred during Operation Iraqi Freedom and Operation Enduring Freedom. This population of service members consists of young, healthy men and women who maintained high levels of activity prior to their injuries and now have goals of achieving or exceeding prior fitness. For those with lower extremity (LE) amputations, approximately 80% of those affected, gait training is an essential part of the rehabilitation process (Esquenazi & DiGiacomo, 2001). Conventional gait training includes therapeutic exercises targeted at functional lower extremity strengthening, weight shifting over the prosthesis, and progressive ambulation. These techniques are applied to ambulation over level surfaces and then more challenging terrain. Depending on the severity of injury, assistive devices may be incorporated with the goal of maintaining quality of motion during ambulation. Research conducted on the efficacy of treatment programs, which have incorporated gait training and re-education for those with LE amputations, have shown improved symmetry in LE kinematics and kinetics, increased self-selected walking speeds, and decreased dependence on assistive devices (Sjodahl et al, 2001, 2002). These studies also found that positive training results remained after a period of six months. Thus, conventional therapies reach the goal of improving functional outcomes as well as producing a lasting effect in those with LE amputations.

The Computer Assisted Rehabilitation Environment (CAREN) [Motek BV, Amsterdam, The Netherlands] at Walter Reed Army Medical Center (WRAMC) allows virtual reality to be incorporated in the gait training of those with LE amputations in addition to conventional therapies. The CAREN is an instrumented treadmill embedded into a six degree-of-freedom motion platform that synchronizes in real time with a virtual environment (VE) projected onto a large, curved screen (Fig. 1). The CAREN is a new and unique device with less than a dozen systems in the world. The system at WRAMC is only one of five with an imbedded treadmill. Due to the rarity and cost of the system, CAREN based research is in its infancy and evidence based treatment recommendations are non-existent. However, promising results have begun to emerge with regard to the feasibility of the system for rehabilitation. In a study by Fung et al (2004), a VE for locomotor training was found to be feasible when utilizing a treadmill mounted on a CAREN motion platform. Using these combined technologies for gait training post-stroke, individuals with chronic stroke were observed to have improved control over gait speed (Fung et al, 2006). Another study concluded that healthy subjects were able to experience a strong sense of immersion during locomotor training with a virtual

©2010 ICDVRAT; ISBN 978 07049 15022

street scene (Yang et al, 2008). These studies illustrate that incorporating VEs with treadmill training has produced positive outcomes. However there is currently no published research on the efficacy of CAREN gait training for those with LE amputations.

The CAREN at WRAMC utilizes a safety stand and full body harness to provide a safe, controlled environment for gait training. Since the treadmill does not include handrails, participants cannot compensate with upper body support and must focus on LE motion. The motion platform has the capacity to allow for and vary inclines, declines and side slopes, which cannot be easily replicated in conventional, indoor therapy settings. The system also permits the settings (e.g. velocity and slope) of each VE to be systematically adjusted to increase or decrease the challenge of each activity; settings are recorded so that the progress of each individual can be followed. Through use of different VEs, the system has the potential to introduce and refine skills that may be encountered in real world situations. The purpose of this retrospective case series is to determine the feasibility of using the CAREN as an adjunct to conventional therapies, for gait training, in individuals with LE amputations. This study also seeks to establish whether a large-scale prospective study is justified. CAREN outcomes of service members, who participated in CAREN clinical rehabilitation sessions, will be examined.

2. METHODS

2.1 Participants

Retrospective chart reviews were performed on 11 service members with traumatic LE amputations; seven unilateral and four bilateral. Table 1 provides an overview of the specific diagnosis and age of each participant; those with similar diagnoses were grouped together. All were male with an average age of 28.9 ± 5.2 years.

Table 1. *Participant diagnosis and age.*

Group	Participant	Diagnosis	Age
1	P1	R – TT	27
	P2	L – TT	27
	P3	L – TT	33
	P4	R – TT	30
	P5	L – TT	21
	P6	L – TT	39
2	P7	R – TF	23
3	P8	R – Midfoot; L – TT	29
	P9	R – Knee disarticulation; L – TT	27
4	P10	Bilateral TF	27
	P11	Bilateral TF	35

R = Right; L = Left; TT = Transtibial; TF = Transfemoral

2.2 Equipment

The CAREN Laboratory at WRAMC has a six-degree-of-freedom motion platform that is 3 meters in diameter (Fig. 1). The platform has the ability to translate approximately 1 meter and rotate up to 18 degrees in any direction. It contains an embedded treadmill, approximately 1.5 meters long by 1.0 meter wide, which has a maximum velocity of 5 m/s. The platform works in combination with a 12 camera motion capture system (Vicon Inc., Oxford, UK) which allows for real time synchronization and interaction with the VEs. VE images are projected onto the 120 degree curved screen, approximately 2.5 meters high by 4.5 meters wide, via two projectors (3D Perception, Asker, Norway) which are blended together to form a single, continuous image. A surround sound audio system may also be utilized. Safety is ensured through the use of a full body harness system.

2.3 Virtual Environments

CAREN gait training at WRAMC incorporates a variety of different VEs. However for the purposes of this case series, outcomes are only reported for the Continuous Road and Road with Overhead Targets applications. These gait applications allowed participants to progress from level walking to inclines, declines, and side-slopes. Both VEs were created using the CAREN D-Flow Software with graphics created in SoftImage (SoftImage Co., Montreal, Canada).

©2010 ICDVRAT; ISBN 978 07049 15022

Figure 1. *Participant walking on the CAREN system during the Continuous Road VE.*

The Continuous Road provided an introduction to locomotion on the CAREN system. This VE began with level walking and allowed each participant to establish a comfortable pace. Once pace was established, the velocity, duration of activity, and grade of platform slope were adjusted based on the recommendations of the treating therapist. To provide the participants with real-time feedback, time and velocity were visually displayed on the screen in their periphery.

The Road with Overhead Targets focused on full body coordination. Reflective markers were placed on the participants' hands so that they could interact with the VE by hitting overhead targets, appearing at random intervals, while walking or jogging over uneven terrain. This terrain included inclines and declines of varying degrees and duration. Time, velocity, and the number of targets hit were displayed.

2.4 Procedures

All participants were referred to the CAREN by their primary physical therapists for clinical rehabilitation. The frequency of visits was determined by the referring therapist and depended on the participant's availability. Each participant was typically scheduled for one or two sessions per week; sessions were 30 minutes in length. Since there were often breaks in rehabilitation to allow for prosthetic changes or to undergo and/or heal from surgical procedures, only participants seen regularly for four to eight consecutive weeks were included in this case series.

Each participant's starting point and progression in the CAREN varied according to their level of injury and phase of rehabilitation. During their initial CAREN session, functional goals were discussed with the referring therapist and the VEs that would be most appropriate for the participant were identified. Consequently, not all participants took part in the same applications. Sessions were divided between treadmill VEs and those considered pre-gait (i.e. weight/step shifting). Too much of any one application type (weight/step shifting or treadmill) has been subjectively reported to cause residual limb pain in prior patients with LE amputations. For all VEs, participants were required to wear a fully body harness and were tethered securely to the CAREN safety stand.

For the Continuous Road and Road with Overhead Targets, participants were instructed to walk at a comfortable pace. The speed of the treadmill was slowly increased until the participant indicated that their desired self-selected velocity had been reached. Participants were given verbal cues by the treating therapist during each application to ensure that quality of motion was maintained. If necessary, the velocity of the treadmill was increased or decreased based on feedback from the treating therapist. The final velocity achieved was recorded for each completed application attempt. Since the Continuous Road had no definitive end, the treating therapist determined when the application was complete. However, for the Road with Overhead Targets the application was considered complete when the patient reached the end of the pathway.

3. RESULTS

3.1 Continuous Road

For the Continuous Road, the velocities for only the first three completed application attempts were examined. This was due to participant progression to the more challenging gait applications, adjustment time required for prosthetic changes, or for surgical procedures. All participants were shown to increase their self-selected velocity for each successive attempt (Fig. 2). The percent change observed for the second and third attempts as compared to the first also increased (Table 2). Participants with bilateral TF amputations, P10

©2010 ICDVRAT; ISBN 978 07049 15022

and P11, had the slowest initial velocities at 0.18 m/s and 0.22 m/s respectively. However, P11 showed the greatest overall percentage increase at 44.4% when comparing the third attempt to the first. P2, with a unilateral TT amputation, achieved the highest initial velocity as well as the highest velocity after the third attempt. With an initial velocity of 1.16 m/s and a final velocity of 1.96 m/s, the overall change observed for P2 was 40.91%.

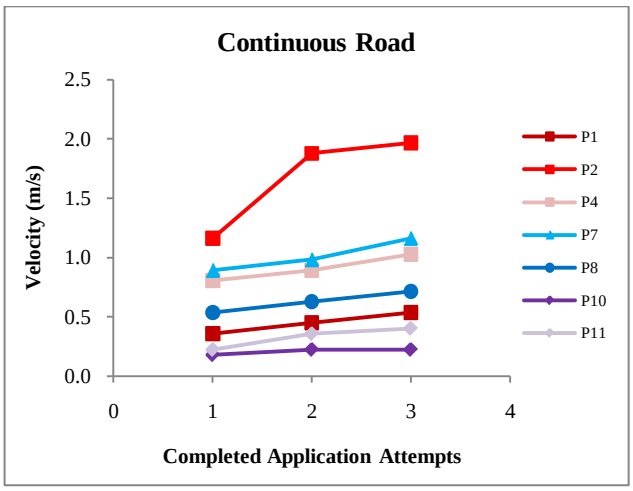


Figure 2. *Velocities (m/s) achieved by each participant for the Continuous Road VE.*

Table 2. *Percent change observed for velocity in the Continuous Road VE.*

	Attempt Comparison	
Participant	**2 vs. 1**	**3 vs. 1**
P1	20.0	33.33
P2	38.1	40.91
P4	10.0	21.74
Group 1 Average	**22.7**	**32.0**
P7	9.91	23.08
Group 2 Average	**9.91**	**23.08**
P8	14.29	25.0
Group 3 Average	**14.29**	**25.0**
P10	10.0	21.74
P11	37.5	44.44
Group 4 Average	**23.75**	**33.09**

3.2 Road with Overhead Targets

For the Road with Overhead Targets, up to five completed application attempts were reported for each participant (Fig. 3). Increased velocities were observed for all participants for the first three attempts. Only P8 and P9, with bilateral TT amputations, were found to decrease in velocity after the third attempt. Even still, the velocities achieved during those final two attempts, were greater than those achieved during the initial attempt. P8 had an initial velocity of 0.49 m/s and a final velocity of 0.63 m/s. P9 had an initial velocity of 0.89 m/s and a final velocity of 1.34 m/s. P5, with a unilateral TT amputation, experienced the greatest change in velocity, 61.36%, when comparing the fifth attempt (1.97 m/s) to the initial (0.76 m/s). The percent changed observed for all participants can be seen in Table 3.

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

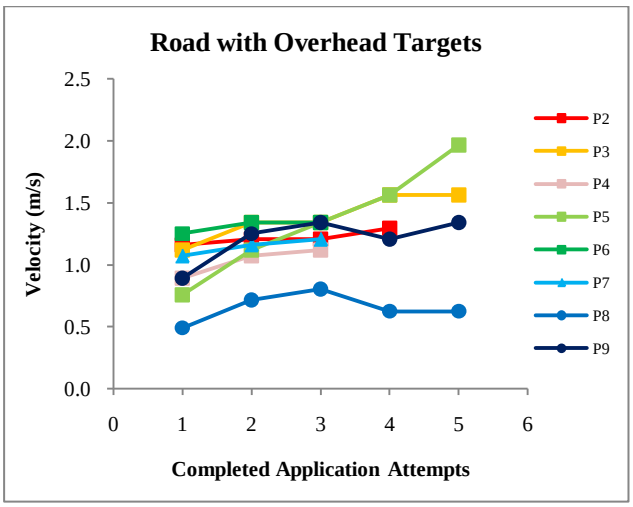


Figure 3. *Velocities (m/s) achieved by each participant for the Road with Overhead Targets VE.*

Table 3. *Percent change observed for velocity in the Road with Overhead Targets VE.*

	Attempt Comparison			
Participant	**2 vs. 1**	**3 vs. 1**	**4 vs. 1**	**5 vs. 1**
P2	3.7	3.74	10.35	--
P3	16.67	16.67	28.57	28.57
P4	16.67	20	--	--
P5	32.0	43.33	51.43	61.36
P6	6.67	6.67	N/A	N/A
Group 1 Average	**15.14**	**18.07**	**30.12**	**44.97**
P7	7.69	11.11	--	--
Group 2 Average	**7.69**	**11.11**	**--**	**--**
P8	31.25	38.89	21.43	21.43
P9	28.57	33.33	25.93	33.33
Group 3 Average	**29.91**	**36.11**	**23.68**	**27.38**

4. DISCUSSION

These preliminary results indicate that CAREN gait training may contribute to greater self-selected velocities for those with LE amputations. However, since the CAREN is currently utilized as an adjunct to conventional gait training techniques, additional research must be conducted to further examine the benefits of this new technology for this purpose.

This case series shows that over periods of four to eight weeks all participants demonstrated increased velocities for the Continuous Road and Road with Overhead Targets. Those with unilateral TT amputations tended to have greater self-selected velocities than those with higher levels of amputation. However, the different progressions observed within each participant group indicate that even with the same diagnosis progression is individual. This is especially true when comorbidities are present. Among the unilateral TT participants, P4 was observed to have lesser changes which may have been due to persistent back pain and P1 had limited range of knee motion due to heterotopic ossification. The only participant with a unilateral TF amputation (P7) had severe LE injuries on his intact side.

For the participants that took part in both VEs (P2, P4, P7, P8), it was observed that the uneven terrain and overhead distractions in the Road with Overhead Targets caused some participants to be more conservative with their self-selected velocity as compared to the Continuous Road. P2 (L - TT) and P8 (R - Midfoot, L - TT) achieved higher velocities in the Continuous Road VE, while P4 (R - TT) and P7 (L - TF) surpassed their prior self-selected velocities. Neither of the participants with bilateral TF amputations took

©2010 ICDVRAT; ISBN 978 07049 15022

part in the Road with Overhead Targets application. Both participants had trouble with socket fit and were not seen again until after the four to eight week period covered in this case series. However, upon their return, each was able to successfully complete the application.

Based on the growing number of clinical referrals it can be inferred that the CAREN has been well-received by participants and therapists. Referring physical therapists have subjectively reported that CAREN gait training has benefited participants by improving confidence and endurance, decreasing reliance on assistive devices, and improving weight shifting over the prosthesis. Improvements have also been noted in overall stride symmetry and in negotiating inclines and declines. The incorporation of a CAREN specific subjective questionnaire in future studies could help to substantiate this feedback and determine whether using the CAREN for gait training does indeed provide practical information to therapists and participants.

Despite the small sample size of this retrospective study, the positive trends identified with regard to self-selected velocity indicate that further investigation of the efficacy of CAREN gait training is warranted for this patient population. A prospective study with a larger sample size could validate this training method and determine whether it helps to facilitate the acquisition of goals by providing additional treatment recommendations for those with LE amputations. Future research could be more structured, controlling for variables such as slope and duration. Kinematic and kinetic data could also be included as well as other conventional outcome measures (e.g. Dynamic Gait Index, 6 Minute Walk, etc.). Unfortunately, in this case series no kinematic or kinetic data was reported because marker sets are minimized for clinical rehabilitation sessions in the CAREN.

Acknowledgements: The author wishes to thank the staff of the Center for Performance and Clinical Research at Walter Reed Army Medical Center for their feedback and support. The views expressed in this paper are those of the author and do not reflect the official policy of the Department of Army, Department of Defense, or U.S. Government.

5. REFERENCES

S Esquenazi and R DiGiacomo (2001), Rehabilitation after amputation, *Journal of the American Podiatric Medical Association, 91, 1*, pp. 13–22.

J Fung, F Malouin, B J McFadyen, F Comeau and A Lamontagne (2004), Locomotor rehabilitation in a complex virtual environment, *Proceedings of the 26th Annual International Conference of the IEEE EMBS*, San Francisco, pp. 4859–4861.

J Fung, C L Richards, F Malouin, B J McFadyen and A Lamontagne (2006), A treadmill and motion coupled virtual reality system for gait training post-stroke, *CyberPsychology and Behavior, 9*, pp. 157–162.

C Sjodahl, G B Jarnlo and B Persson (2001), Gait improvement in unilateral transfemoral amputees by combined psychological and physiotherapeutic treatment, *Journal of Rehabilitation Medicine*, 33, pp.114–118.

C Sjodahl, G B Jarnlo, B Soderberg and B Persson (2002), Kinematic and kinetic gait analysis in the sagittal plan of trans-femoral amputees before and after special gait re-education, *Prosthetics and Orthotics International, 26*, pp. 101–112.

Y R Yang, M P Tsai, T Y Chuang, W H Sung and R Y Wang (2008), Virtual reality-based training improves community ambulation in individuals with stroke: A randomized controlled trial, *Gait & Posture, 28*, pp. 201–206.

©2010 ICDVRAT; ISBN 978 07049 15022

Continuation of balance training for stroke subjects in home environment using virtual reality

I Cikajlo, M Rudolf, N Goljar, Z Matjačić

University Rehabilitation Institute, Linhartova 51, Ljubljana, SLOVENIA

imre.cikajlo@ir-rs.si

http://www.ir-rs.si

ABSTRACT

The objective of the telerehabilitation is a continuation of the rehabilitation process on subjects' home and making the therapists and physicians possible to follow the progress remotely. Hereby the pilot project with virtual reality based tasks for dynamic standing frame supported balance training is presented. Six stroke subjects participated in the preliminary study. The subjects performed the therapy five times a week, each time for up to 20 minutes for three weeks. The results were evaluated by objective game parameters as track time, number of collisions and clinical instruments Berg Balance Scale, Timed Up&Go and 10m walk test. The outcomes demonstrated a significant improvement of all parameters. However, the follow up after two weeks demonstrated that functional improvement could be possible on a long term, if the subjects continue with targeted tasks for extended period of time. Besides, the balance training could be continued on subject's home instead of the hospital, which would decrease the number of outpatients' visits and reduce related costs.

1. INTRODUCTION

One of the important issues in stroke population is balance control. The loss of balance in most cases results in fall and consequently in injuries. Therefore the restoration of static and dynamic balance is important for restoration of functional capabilities of stroke subjects. The outcome of research performed in the USA and UK in a group of stroke subjects demonstrated that functional capabilities may improve with rehabilitation in acute and chronic phase, when intensive therapy with repeatable and targeted tasks are applied (Kwakkel et al, 1999). The therapy in these conditions in clinical environment is assured by assistive devices that can assure safety. On the other hand these devices are ready for targeted tasks application in repeatable conditions. The person with severe stroke using assistive devices during hospital treatment require less physical effort of the medical staff, who can now focus on person and his/her task performance. The improvement of functional status can be achieved by applying target oriented tasks. Among such tasks is a simple ball catching or more complex task requiring person's attention and intervention in virtual reality (VR) environment (Holden, 2005). The task built up in VR enable a gradual increase of task's difficulty level, speed, sensitivity, specific goal and can be adopted to the subject's cognitive and motor capabilities (Cikajlo et at, 2009). VR supported therapy can improve balance capabilities in hemiparetic subjects with stroke when combined with conventional therapy (Kim et al, 2009) and on top of that when built up as computer games presents an additional motivation for subject (Rizzo et al, 2004).

But the main issue remains the limited time dedicated to the rehabilitation due to the financial limits of the health insurance system. It turns out that most of the subjects discontinue with any kind of activity that would enhance their functional capabilities when they are discharged from the rehabilitation hospital. Therefore it is important to give them an opportunity to continue with the motivating tasks they are familiar with. Nowadays the information-communication technologies (ICT) are ready to transfer video, audio, secure data and graphics in real-time and play a major role in telerehabilitation. The VR therapy can continue in remote rehabilitation center, local hospital or even on subject's home. This may lead to the shortening of inpatient hospital treatment and continuation of rehabilitation process (e.g. balance training) on subject's home. Besides, the telerehabilitation in combination with telediagnostics may decrease the number of required outpatient visits (Cikajlo et al, 2009).

Hereby we present a development of a VR supported balance training using the dynamic standing frame (Matjačić et al, 2000), which assures safety with limited range of motion and provide support during vertical

©2010 ICDVRAT; ISBN 978 07049 15022

posture. The designed task in VR was used in target oriented balance training in the rehabilitation hospital in six subjects with stroke who also continued with the therapy all by themselves in the smart home. Only the physiotherapist supervised the therapeutic process occasionally via web browser and videoconference. In participating subjects also the clinical tests (Berg Balance Scale, Timed Up&Go and 10m walk test, standing on a single extremity) were carried out. We expected that the clinical tests would demonstrate rapid improvement of functional balance performance, which would not decline immediately after the therapy.

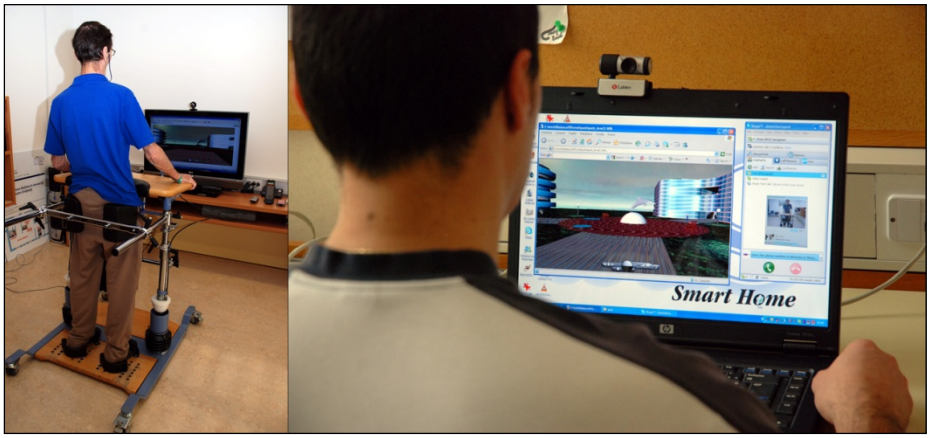


Figure 1. *Balance training with task in virtual environment could be continued on subject's home (left). Therapist (right) supervised and advised the subject through the videoconference and followed the task performance in the Internet Explorer.*

2. METHODOLOGY

2.1 Subjects

Six subjects with stroke (58.5 SD 12.1 years, 84.3 SD 11.5 kg, 176.3 SD 5.7 cm) participated in the VR therapy at the Institute's hospital and in the development of telerehabilitation based pro-longed therapy. The subjects with stroke were selected on the basis of the inclusion criteria:

- show minimal ability to maintain upright posture and balance while standing in the standing frame,
- passed the cognitive test,
- checked cardiovascular status,
- subject has not taken any medications. Clinical examination was done by authorized medical personnel.
- subject had no prior experience with the dynamic balance and standing frame.

The methodology was approved by ethics committee of the University rehabilitation institute, republic of Slovenia and the subjects gave informed consent.

2.2 Equipment

In the last decade we have developed an assistive device for balance training in safe conditions, a dynamic standing frame, which was commercialized by a German company (Medica Medizintechnik, Germany) and is known as the BalanceTrainer (BT), a simplified passive device for balance training. The balance training standing frame (Figure 1. left) is made of steel base construction placed on four wheels, which when unlocked enable the apparatus mobility. The standing frame is made of aluminum and fixed to the base with passive controllable spring defining the stiffness of the two degrees of freedom (2 DOF) standing frame. The stiffness of the frame is set up according to the individual's requirements. On the top of the standing frame a wooden table with safety lock for holding the subject at the level of pelvis was mounted. The standing frame can tilt in sagital and frontal plane for ± 15^{o}.

The tilt of the frame was measured by commercially available three-axis tilt sensor (Xsens Technologies, Enschede, The Netherlands) and the action movement immediately resulted in the designated virtual environment. The virtual reality (modeled in VRML 2.0, running in MS Internet Explorer with blaxxun contact plug-in) based task required from the subject to "walk" by tilting the frame forward and "turn" by tilting the frame left or right. Figure 2 presents the path that was accomplished in several repetition of the VR task in one session (5 min.). The system also registered and counted the number of collisions with VR objects and measured the time that was needed to finish a single task (from START to END point).

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

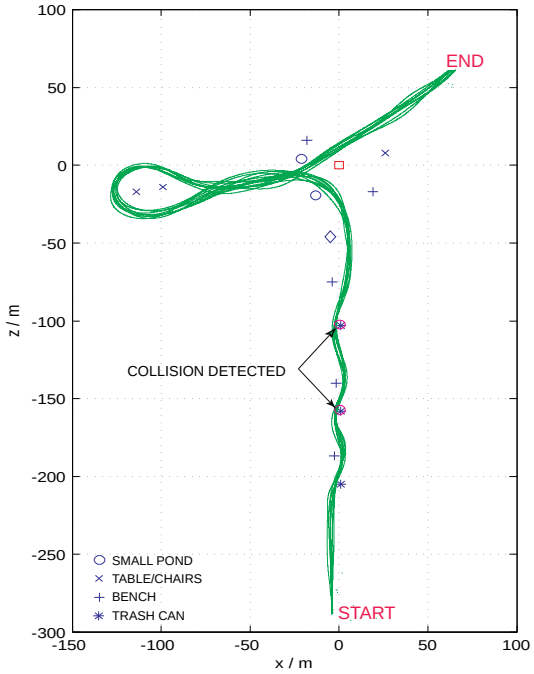


Figure 2. *Path accomplished during the VR supported therapy.*

2.3 Protocol

The subject was standing in vertical position in the balance trainer with his hands placed on the wooden table in front of him and secured with safety lock from behind at the level of pelvis, enabling tilting forward, backward, left, right and all combination, but preventing to fall backward. The speed of "walk" or "turn" was proportional to the frame tilt angle. The subjects walked through the virtual environment on the path suggested by the therapist and were trying to avoid collision with the objects like can, bank, pool, tables, chairs, people... etc. At last they entered the building and the task started over and over again. During the activity the task time and number of collisions were detected and at the end presented to the subject. All the subjects needed additional assistance during balancing at the beginning of the task performance in rehabilitation hospital. After two weeks of the VR supported balance training they were set in the smart home environment and performed the task on their own. The tasks were designed to run in a web-explorer allowing the medical professionals to supervise (Figure 1. right), monitor and control the balance training process remotely through the World Wide Web. Besides, the videoconference enabled the physiotherapist to give the subject an important advice during the dynamic balance training, e.g. to correct the posture, hand placement, etc.

The subjects performed the therapy (VRBT – virtual reality balance training) five times a week, each time for up to 20 minutes for three weeks. The results were evaluated by objective game parameters as track time, number of hits and clinical instruments Berg Balance Scale, Timed Up&Go (TUG) and 10m.

Table 1. *The protocol timetable.*

clinical assessment	1. week	2. week	3. week	clinical assessment	4.-5. week	clinical assessment
	activity	activity	activity		no activity	
	VRBT	VRBT	VRBT		no BT	
	hospital	hospital	Smart home		-	

©2010 ICDVRAT; ISBN 978 07049 15022

3. RESULTS

The task time was shorter for 42.7s (45%) and the subjects committed in average 6 (68%) collisions fewer (Figure 3). The collisions with objects were averaged on single VR task ("lap") and a linear regression (Paerson's coefficient) with VR task time demonstrated high level of agreement, R = 0.80 (Figure 3). This confirmed our observations that subjects who managed to accomplish the task faster, also collided with fewer obstacles.

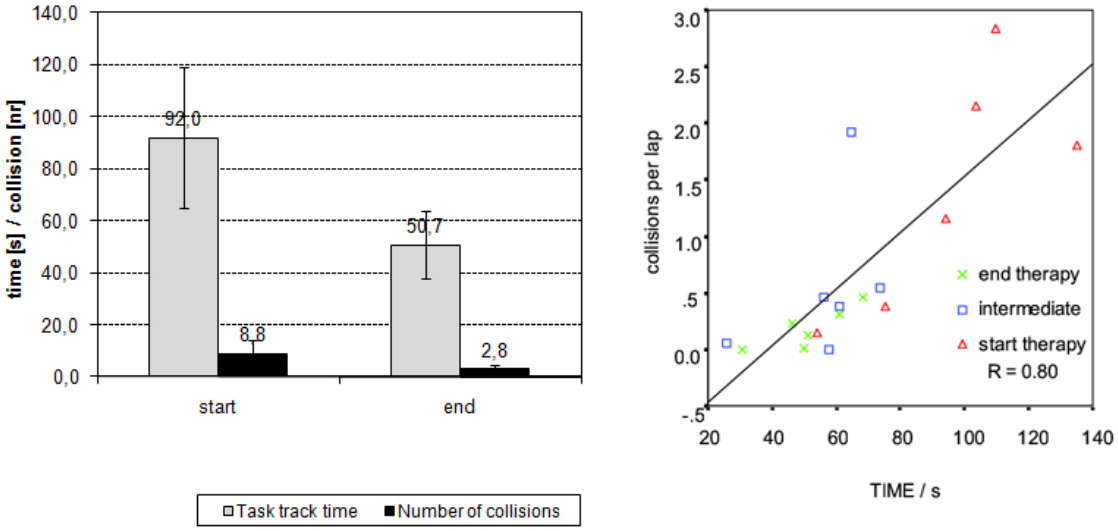


Figure 3. *Measured outcomes. The subjects accomplished the VR task significantly faster with fewer collisions with objects after therapy. The "score" was also considered a motivation factor for each individual. Number of collisions normalized per task (lap) correlated well with the task time.*

The Figure 4 shows clinical outcomes (10m test, TUG, BBS, standing on affected extremity - AE, standing on the healthy extremity - HE) of the participating subjects. The mean and standard deviation (SD) values for all subjects prior, after the training and the follow up are presented. All observed parameters have improved with training, although the assessment of the AE and also of the HE was not possible prior to the therapy for all subjects due to the impairment. Some subjects also used an additional walk aid or/and needed therapist's assistance (a reason for higher SD). The BBS score improved from 37/56 to 42/56, standing on one leg was longer for HE up to 10s and AE up to 4s. The subjects also improved their TUG time in average for 10.0s and 10m walk time in average for 4.6s.

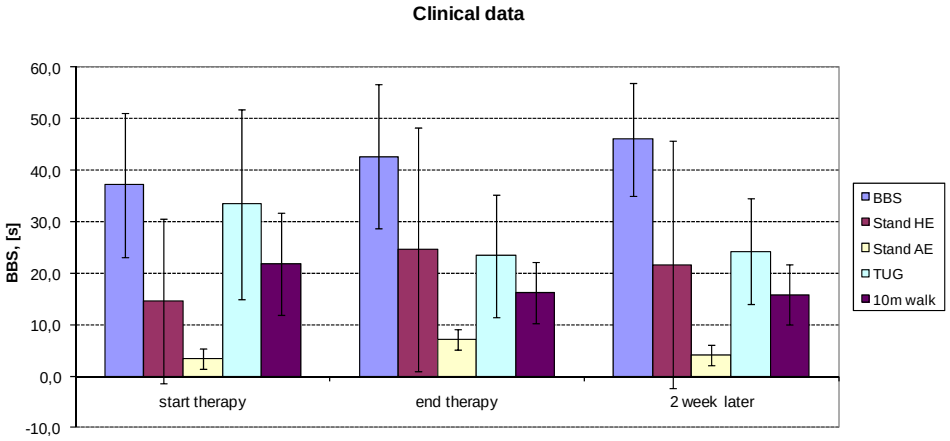


Figure 4. *Clinical outcomes in subjects who participated in balance training with virtual reality tasks and the follow up after two weeks.*

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

4. DISCUSSION

All participating subjects were able to accomplish the VR task faster at the end than at the beginning of the therapy and commit fewer collisions with obstacles. This can be attributed to the fact that the subjects mastered the exercise, as well as their balance abilities improved. The later is evident from fewer collisions which force the participating subject to transfer the load to the medial extremity and overcome the VR obstacle; otherwise the collision would be unavoidable. The improved balance abilities were evident from the BBS improvement and also from the fact that most of them could stand on the affected extremity, which was not possible for all subjects prior to the therapy. The gait clinical tests 10m walk and TUG also demonstrated significant improvement, which resulted in better overall mobility. Summarizing the outcomes we may claim that the functional balance status of the participating subjects has significantly improved. The outcomes obtained in the study were similar to the results of the study (Goljar et al, 2010) performed in two randomized group of subjects. The first group used only the same balance training device but without VR task, while the control group received conventional therapy only. Goljar et al did not find a significant difference between the two groups. However, the improvement of balance abilities was also comparable with the proposed VR balance training and the participating subjects' status remained the same after two weeks despite they had no balance training. Also we have not noticed any postural instability or VR sickness as a consequence of immersions in dynamic VR environment, thus we are aware of subjective physical experience of moving. The limitation in field of view may also have had impact on performance (Nyberg et al, 2006) as well as the problems in cognitive processing due to conversion of tilting into "walking". Also the VR supported learning may not be always transferrable to the real world applications or be effective immediately in the real world (Rose et al, 2000).

5. CONCLUSIONS

The telerehabilitation presents a novel approach in treatment of subjects with neuromuscular injuries or diseases (Lai et al, 2010). The proposed approach is not based only on teleconsulting which is indeed indispensable, but also supervises, controls and guides the therapy process remotely via internet. The clinical outcomes are comparable with conventional therapy and passive device supported balance training, but allows the patients more independence and earlier return home. Besides, the physiotherapists are relieved from strenuous manual work. The proposed approach also takes in consideration an economic view (Dhurjaty, 2004) since the number of outpatient visits could be reduced. Besides that the return home had positive effects on the motor performance of the subjects and one of the most important issues was that the subjects expressed personal satisfaction (Piron et al, 2008).

Acknowledgements: The authors would like to acknowledge the financial support of the Slovenian Research Agency (Grant Nr. P2--0228).

6. REFERENCES

G Kwakkel, R C Wagenaar, J W R Twisk, et. al . (1999), Intensity of leg and arm training after primary middle- cerebral- artery stroke: A randomised trial, *Lancet*, **354**, pp. 191- 196.

Z Matjačić, I L Johannesen and T Sinkjaer (2000), A multi - purpose rehabilitation frame: A novel apparatus for balance training during standing of neurologically impaired individuals. *J. Rehab. Res. Dev*., **37**, pp. 68-91.

M K Holden (2005), Virtual environments for motor rehabilitation: Review. *Cyber Psychol Behav.,* **8**, pp.187-211.

F D Rose, E A Attree, B M Brooks, D M Parslow, P R Penn and N Ambihaipahan (2000), Training in virtual environments: Transfer to real world tasks and equivalence to real task training. *Ergonomics,* **43**, pp. 494-511.

L Nyberg, L Lundin-Olsson, B Sondell, A Backman, K Holmlund, S Eriksson, M Stenvall, E Rosendahl, M Maxhall and G Bucht (2006), Using a virtual reality system to study balance and walking in a virtual outdoor environment: a pilot study, *Cyberpsychol Behav*., **9**, 4, pp. 388-395.

N Goljar, H Burger, M Rudolf and I Stanonik (2010), Improving balance in subacute stroke patients: a randomized controlled study, *Int J Rehabil Res*. **12,** 1 pp. - Epub ahead of print.

©2010 ICDVRAT; ISBN 978 07049 15022

I Cikajlo and Z Matjačić (2009), Advantages of virtual reality technology in rehabilitation of people with neuromuscular disorders , In *Recent advances in biomedical engineering* (NAIK, Ganesh R, Ed.), In-Tech, , Vienna, pp. 301–320.

I Cikajlo and Z Matjačić (2009), Directionally specific objective postural response assessment tool for treatment evaluation in stroke patients, *IEEE Trans Neural Syst Rehabil Eng* **17,** 1, pp. 91–100.

J H Kim, S H Jang, C S Kim, J H Jung and J H You (2009), Use of virtual reality to enhance balance and ambulation in chronic stroke: a double-blind, randomized controlled study, *Am J Phys Med Rehabil*. **88**, 9, pp. 693–701.

L Piron, A Turolla, P Tonin, F Piccione, L Lain and M Dam (2008), Satisfaction with care in post-stroke patients undergoing a telerehabilitation programme at home, *J Telemed Telecare*. **14,** 5, pp. 257–260.

A A Rizzo, D Strickland and S Bouchard (2004), The challenge of using virtual reality in telerehabilitation, *Telemed J E Health*. **10,** 2, pp. 184–195.

J C Lai, J Woo, E Hui and W M Chan (2004), Telerehabilitation - a new model for community-based stroke rehabilitation, *J Telemed Telecare*.**10**, 4, pp. 199–205.

S Dhurjaty (2004), The Economics of Telerehabilitation, *Telemed J & e-health*. **10**, 2, pp. 196–200.

©2010 ICDVRAT; ISBN 978 07049 15022

Audio-visual biofeedback system for postural control

M Milosevic, K M V McConville

Electrical Engineering Department, Ryerson University
350 Victoria Street, Toronto, M5B 2K3, Ontario, CANADA

mmilosev@ee.ryerson.ca, kmcconvi@ee.ryerson.ca

ABSTRACT

This study presents an application of biofeedback in balance training, in particular an audio-visual balance rehabilitation system designed for training of the elderly. Motivated by the need to provide portable, cost-effective and accessible training devices, the system implements a MEMS accelerometer to quantify the balance board movements during a balancing task and use them to provide a real-time, synchronous audio-visual biofeedback. The visual feedback displays the offset and the overall performance of the balance board. The audio feedback is based on the sound localization cues that indicate the direction of the balance board movements using stereo sound. Initial results indicate a significant improvement in the postural stability when the audio-visual biofeedback is provided. The pilot study found significant improvements in maintenance and recovery of dynamic balance manifested through decreased variability of complex, lateral and front-to-back movements during a balancing task.

1. INTRODUCTION

Recent studies (e.g. Rubenstein, 2006) have shown that falls are the most frequent cause of injuries in the general populations and it is known that the incidence and severity of falls increases with age. It has been shown that falls are leading cause of some 300,000 hip fractures in the United States. The healthcare cost in the United States has been associated with the approximately $US 10 billion (Maki et al., 2003). It has been projected that falls will become an increasingly growing healthcare and societal problem because of the graying baby-boomer generation and projections indicate that the cost and the impact will quadruple in the next forty years. Our analysis (Milosevic and McConville, 2007a) of the 2005 Canadian Community Health Survey found that among Canadians, falls cause the most serious injuries in adults over 65 years of age. Also, this study found that slips, trips and stumbles frequently occur among the elderly and represent one of the major causes for falls-related injury.

Stevens and Olson (2000), advocate development of new approaches to prevention including behavioral and environmental changes as well as the development of new exercise programs aimed to improve strength and balance among the elderly. The reviews of evidence on falls and the prevention of falls (Rubenstein, 2006; Rubenstein and Josephson, 2006; Horak, 2006) indicate the existence of knowledge gaps related to clinical diagnostic procedures, cost-effective balance diagnostic equipment, and balance exercise programs. According to these studies, a highly important factor in the prevention of falls is the development of feasible and cost-effective tools along with the appropriate training programs for improvement of balance.

Balance is most affected by the visual, vestibular and proprioceptive system inputs, all of which deteriorate significantly with age. Balance control is a complex skill based process based on integrated sensory system re-weighing (Horak, 2006). The focus of rehabilitation strategies has gone from the compensatory to the neurorestorative recovery strategies. Thus it is important to consider the underlying neurological fundamentals and constraints. The specific strategies can also consider augmenting the compensatory mechanisms with adjacent strategies to have the most effect (Dobkin, 2003). This indicates that biofeedback can be an important tool, not only for neural rehabilitation, but for developing assistive devices for continual and portable feedback provision.

Studies, investigating audio and visual feedback modalities, found positive effects of audio-feedback and visual-feedback on improvements of balance. They suggest that audio and visual information can successfully provide feedback information during balancing tasks. Dozza, Chiari and Horak (2004) investigated a training system based on a portable audio-biofeedback (ABF) device that uses accelerometric signals encoded into stereo sound and demonstrated a significant balance improvement among healthy

©2010 ICDVRAT; ISBN 978 07049 15022

subjects. Another study (Dozza et al., 2005) examined the effects of the ABF systems on upright stance postural stability, in conditions of limited and unreliable sensory information among healthy subjects. They provided evidence that the audio-biofeedback system improves postural stability. In addition to the previously identified positive impact of biofeedback (BF) systems, a recent investigation of BF training using coding of audio and visual information for control of posture (Dozza et al., 2006) showed significant differences in the effects of audio and visual information cues on posture control. Results from this study showed that audio BF was more important for reducing center of pressure displacement while visual BF had a more important role in reducing trunk sway.

Our study examines a new system that uses both audio and visual feedback in balance maintenance through provision of different information for control of dynamic balance. The objective of the study was to develop a portable, cost-effective and accessible training device that uses biofeedback to provide audio and visual information about the balance performance during dynamic balancing.

2. METHODS

2.1 Subjects

The study examined four healthy participants who performed the experimental tasks consisting of three different tests with and without the audio-visual biofeedback. The mean age of the participants was 36.8 years and two are male and two are female. All of the participants were healthy middle-aged adults with no history of neurological or other disease, no history of falls, and vestibular or musculoskeletal impairments that might restrict them in participating.

2.2 Dynamic Balance Task

The effectiveness of the audio-visual biofeedback system was assessed during a dynamic postural stability balance task. The postural stability balance task consists of maintaining balance on an exercise balance board (PT Balance Board, PTfitness). The balance board is a simple yet valuable training and assessment device for use in therapeutic practice and in studies of dynamic postural balance. The balance board has been shown as a valuable training and assessment device (Dozza et al., 2006; Ferrell et al., 2004; Nordt et al., 1999). Mechling (1986) has demonstrated similar results between the measurements obtained from a force platform and a variable resistance balance board during stance. This study provides the evidence that balance boards are a valid and practical clinical assessment tool for diagnostic of dynamic balance.

The participants were tested on the three types of the balance boards with: (1) audio-visual biofeedback and (2) no biofeedback for each of the balancing tasks. The balance tasks include the balance board that can move in all direction: Radius; balance board that can move in the front-to-back directions only: Front-to-back; and the balance board that move in the left-right directions only: Lateral. The balancing tasks include quietly standing and trying to maintain balance with the arms positioned flat against the body. The effect of the audio-visual biofeedback for each balance board was recorded over a period of one-minute. The outcome measures included radius, and the lateral and front-to-back directions dynamics of the balance board movements.

2.3 Data Acquisition and Analysis

The balance board dynamics in the front-to-back and lateral directions were quantified using data from MEMS accelerometers (Kionix Inc., USA, model KXM52-1050, 3-axial accelerometer with a range of ±2.0g and sensitivity of 660 mV/g). Signals were sampled and acquired using a 12-bit data acquisition system (National Instruments, USA) for further processing on the personal computer. Signal processing was performed using LabVIEW 8.0 (National Instruments, USA) where the visual and audio analysis was performed and the feedback presented in real-time. The statistical analysis post-processing was performed using SPSS for Windows (SPSS, Inc.) and Statistica (StatSoft, Inc.).

2.4 Biofeedback Overview

The biofeedback system consists of real-time combined audio and visual feedback that indicates the position and direction of the balance board during the balancing task based on the accelerometer readings. In a study on audio-feedback Huang et al. found (2006), that sound is an effective feedback for temporal information, and that visual information works better for spatial feedback (Huang et al., 2006; Huang, Wolf and He, 2006). Also, several studies in the SPIRALL Laboratory at Ryerson University demonstrated a positive impact of virtual reality training on postural balance (McConville, Virk and Milosevic, 2007); Virk et al, 2007). This group of studies also found a beneficial effect of active use of arms and increased awareness

©2010 ICDVRAT; ISBN 978 07049 15022

about the role of arm movements for balance maintenance and recovery (Milosevic and McConville, 2007a; Milosevic and McConville, 2007b).

Specifically, the biofeedback system uses the visual information that shows balance board position and the audio information about the balance board dynamic. The combined processing and feedback was expected to provide an increased spatial orientation and improve maintenance and recovery of postural balance. The block diagram (Figure 1) presents the information flow from the sensor (accelerometer that is placed on the balance board and measures the dynamics of subject's movements), to the computer that process the acquired data, and provides the real time audio and visual biofeedback. In addition, the system stores the data in the database for further offline analysis.

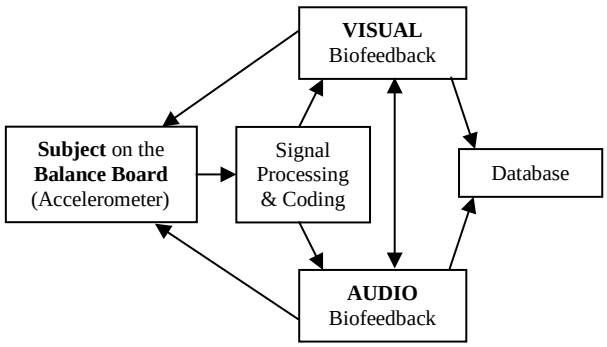


Figure 1. *Block diagram representation of the biofeedback system.*

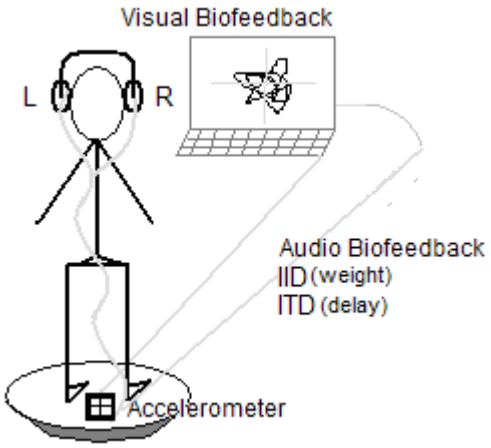


Figure 2. *System implementation for the audio-visual biofeedback. The subject is watching the visual display screen and at the same time receiving the stereo sound with the sound localization algorithm on the headphones.*

2.4.1 Visual Biofeedback. The visual biofeedback is displayed to the user on the PC station 15.4" flat-screen monitor. The visual display consists of a two-dimensional coordinate system plot that presents the position of the balance board related to the lateral (X) and front-to-back (Y) axes. Traces of the X and Y position indicate the dynamics of movement in the polar coordinate system and provide a visual display of the movements during the entire test session. The plot also keeps the position of all previous samples, for each reading, providing the overall performance feedback and the variance of the movement performance visually (Figure 2).

Considering the deteriorating sensory perception among the elderly the implemented display has the goal of augmenting the complex environment and as such helping improve balance. As the goal of the rehabilitation process is to provide the perceivable and simplified information about the often non-perceivable and complex environment for the elderly, the display is designed with this in mind. Moreover, based on the knowledge about the changing and increasingly symmetrical visual memory processes among the elderly (Dobkin, 2003, Dobkin, 2004, Peters, 2005) it is expected that the visual display will have a role in establishing new processes and can have implication in re-weighing the sensory inputs used for balancing

©2010 ICDVRAT; ISBN 978 07049 15022

(Horak, 2006) through cortical plasticity induced by task-specific, repetitive, biofeedback training (Dobkin, 2003).

2.4.2 Audio Biofeedback. The audio biofeedback is provided to the user via stereo headphones. The feedback works by calculating the time difference offset and varying the amplitude of the left and the right headphone speaker, based on the algorithm for sound source localization. The Interaural Intensity Difference (IID) algorithm changes the amplitude of the delivered sound signal to each ear based on the position of the balance board. The intensity of the sound increases proportionally to the direction of the balance board. According to previous studies, the algorithm is the most effective when sound was transmitted with headphones (Dodge and Jerse, 1997). Furthermore, the Interaural Timing Difference (ITD) algorithm delivers a slightly delayed sound signal to the ear further away from the direction of the balance board, because of the apparent longer direction of travel providing the feeling that the virtual sound source is in the direction the balance board offset. The ITD has been shown to perform best in the lower frequency range (Dodge and Jerse, 1997). The IID and ITD algorithms were implemented on a constant sinusoidal sound source at 200 Hz and are presented to the subject to provide the audio-directional information. Figure 2 shows implementation of the audio biofeedback system.

Numerous studies on the risk of falls found than people prone to falls suffer from auditory impairment (Chu, et al., 2004; Sihvonen et al., 2004; Stevens et al., 2008) this study devotes particular attention to activation of the existing auditory sensory capabilities for supporting balance maintenance and recovery. The algorithm for the audio feedback used in this study is based on the neural mechanisms of encoding binaural localization cues in the auditory brainstem. According to theory, the auditory system is biologically important for vertebrates because it provides information about the direction and distance of sound. The algorithm for audio feedback is based on the principles of sounds encoding and interpreted through the integrative role of the CNS that gives meaning, localizes and interprets the source and meaning of sound. According to Yin (2002), sound localization is a critical task for the auditory system and the modern neurobiological research explains how vertebrates identify the source and localize sounds form the surrounding environment.

3. RESULTS AND DISCUSSIONS

The effectiveness of the audio-visual biofeedback system was tested in this study and shows promising results. The analysis includes comparison of repeated one-minute balancing tasks on the balance board with: (1) audio-visual biofeedback and (2) no biofeedback during the balancing tasks. All participants were introduced to the balancing tasks through a test practice run and were acquainted with the audio-visual system. The outcome measures include radius, and the lateral and front-to-back directions of the balance board dynamics (Table 1). The results indicate significant improvements in postural stability expressed through decreased variance of the balance board movements. Results show decreased mean of Radius ($F= 926.023$, $p<0.0001$), Lateral ($F= 125.973$, $p<0.0001$) and Front-to-back ($F=65.945$, $p<0.0001$) balance board movements. In addition to the decreased average movements the results show significant variance decrease among all participants (Fig. 3-5). The decreased radius of the balance board movements (Fig. 3) suggests an overall improvement in dynamic balance maintenance with the audio-visual biofeedback. The study also shows improvements in both, the front-to-back (Fig. 5) balancing task and the lateral (Fig. 4) balancing task which is particularly important for falls prevention among the elderly (Maki and McIlroy, 2006).

Table 1. *Descriptive statistics and ANOVA results for comparison of (1) Biofeedback and (2) No Biofeedback balance board dynamics.*

	Radius		**Lateral**		**Front-to-back**	
	Mean	SD	Mean	SD	Mean	SD
(1) Biofeedback	0.086446	0.026325	0.027684	0.022705	-0.07797	0.028405
(2) No Biofeedback	0.11534	0.050989	0.036869	0.043948	-0.08807	0.069697
ANOVA	F= 926.023 p<0.0001		F= 125.973 p<0.0001		F= 65.945 p<0.0001	

©2010 ICDVRAT; ISBN 978 07049 15022

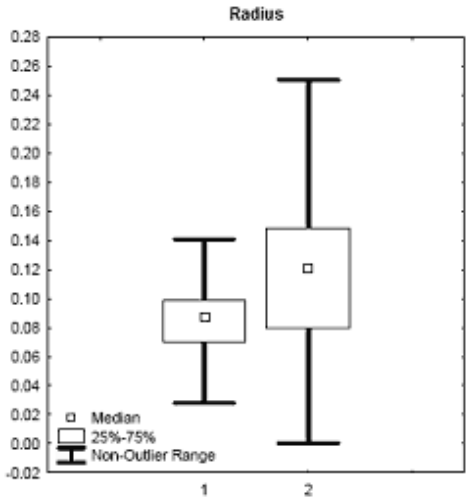


Figure 3. *Radius of the balance board movements*

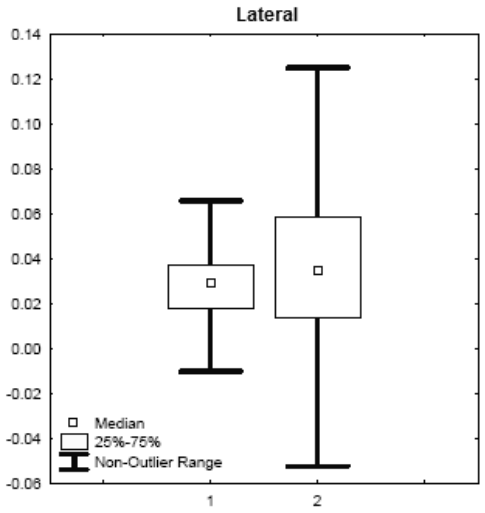


Figure 4. *Lateral balance board dynamics.*

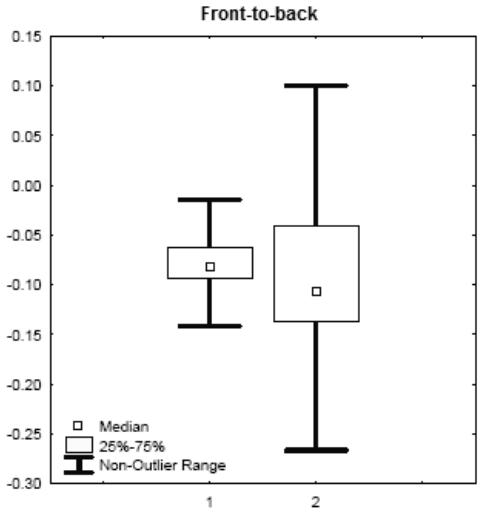


Figure 5. *Front-to-back balance board dynamics.*

4. CONCLUSION

The study presents the results during the implementation of a cost-effective and portable balance training system for the elderly. The initial results of this study indicate a significant positive impact of the combined audio-visual biofeedback on dynamic balance. Analysis shows a decrease in the overall variability of the balance board movements and better maintenance of balance when using the biofeedback. The results suggest that this system can provide a useful training tool for the elderly with an impaired sensory-motor control system. Further developments of this system and a more inclusive feedback, targeting specific movement strategies, may provide training for specific and more efficient balance maintenance strategies. Overall, the study presents promising results and calls for further investigation of the combined audio-visual feedback in improving balance in the elderly, as well as the temporal effects on balance improvements.

Acknowledgements: The authors acknowledge the Natural Sciences and Engineering Research Council (NSERC) of Canada (Grant No.54196), for supporting this work. The authors would like to thank Prof. Ling Guan of Ryerson University for his useful suggestions and help.

5. REFERENCES

B E Maki and W E McIlroy (2006), Control of rapid limb movements for balance recovery: age-related changes and implications for fall prevention, *Age Ageing*, **35** *Suppl 2*, pp. ii12-ii18.

B E Maki, W E McIlroy and G R Fernie (2003), Change-in-support reactions for balance recovery, *IEEE Eng Med Biol Mag*, **22**, *2*, pp. 20-26.

B H Dobkin (2003), *The clinical science of neurologic rehabilitation* (2nd ed.). New York: Oxford University Press.

B H Dobkin (2004), Strategies for stroke rehabilitation. *Lancet Neurol*, **3**, 9, pp. 528-536.

C Dodge and T A Jerse (1997), *Computer Music: Synthesis, Composition, and Performance*, 2nd ed. New York: Schirmer Books.

F B Horak (2006), Postural orientation and equilibrium: what do we need to know about neural control of balance to prevent falls?, *Age Ageing*, **35** *Suppl 2*, pp. ii7-ii11.

H Huang, S L Wolf and J He (2006), Recent developments in biofeedback for neuromotor rehabilitation, *Journal of NeuroEngineering and Rehabilitation*, **3**, pp. 11.

H Huang, Y Chen, W Xu, H Sundaram, L Olson, T Ingalls, T Rikakis and J He (2006), Novel design of interactive multimodal biofeedback system for neurorehabilitation, *IEEE Conference Proceedings: Engineering in Medicine and Biology*, **1**, pp. 4925-4928.

J A Stevens and S Olson (2000), Reducing falls and resulting hip fractures among older women. In: CDC Recommendations Regarding Selected Conditions Affecting Women's Health, *MMWR Morbidity and Mortality Weekly Report*, **49**, *RR-2*, pp. 3-12.

K N Stevens, I A Lang, J M Guralnik and D Melzer (2008), Epidemiology of balance and dizziness in a national population: findings from the English Longitudinal Study of Ageing. *Age Ageing*. **37**, *3*, pp. 300-305.

K V M McConville, S Virk and M Milosevic (2007), Head Movement Effects in a Cost-Effective Virtual Reality Training Environment for Balance Rehabilitation", *Proceedings of International Workshop on Virtual Rehabilitation*, 27-29 Sept. 2007 Venice, Italy, pp. 87.

L Z Rubenstein (2006), Falls in older people: Epidemiology, risk factors and strategies for prevention, *Age Ageing*, **35**, pp. ii37-ii41.

L Z Rubenstein and K R Josephson (2006), Falls and their prevention in elderly people: what does the evidence show?, *Med Clin North Am*, **90**, *5*, pp. 807-824.

M Dozza, L Chiari and F B Horak (2004), A portable audio-biofeedback system to improve postural control, *IEEE Conference Proceedings: Engineering in Medicine and Biology*, **7**, pp. 4799-4802.

M Dozza, L Chiari, B Chan, L Rocchi, F B Horak and A Cappello (2005), Influence of a portable Audio-biofeedback device on structural properties of postural sway, *Journal of NeuroEngineering and Rehabilitation*, **2**, pp. 13.

M Dozza, L Chiari, F Hlavacka, A Cappello and F B Horak (2006), Effects of linear versus sigmoid coding of visual or audio biofeedback for the control of upright stance, *IEEE Transactions on Neural Systems and Rehabilitation Engineering*, **14**, *4*, pp. 505-512.

©2010 ICDVRAT; ISBN 978 07049 15022

M Milosevic and K M V McConville (2007a), Falls Prevention among Older Adults through Rectification of Hand Movements Based on a Novel Method for Quantitative Balance Assessment, presented at *The 2007 FICCDAT - Festival of International Conferences on Caregiving, Disability, Aging and Technology*, Toronto.

M Milosevic and K M V McConville (2007b), Arm Movements in Balance Maintenance and Recovery Based on Quantitative Balance Assessment, *Motor Control*, **11**, pp. S167-S168.

R Peters (2005), Ageing and the brain. *Postgraduate Medical Journal*, **82**, 84-88.

R W Mechling (1986), Objective assessment of postural balance through use of the variable resistance balance board, *Physical Therapy*, **66**, *5*, pp. 685-688.

S P Chu, J L Kelsey, T H Keegan, B Sternfeld, M Prill, C P Quesenberry, et al. (2004), Risk factors for proximal humerus fracture. *Am J Epidemiol*, **160**, *4*, 360-367.

S Sihvonen, P Era and M Helenius (2004), Postural balance and health-related factors in middle-aged and older women with injurious falls and non-fallers. *Aging Clin Exp Res*, **16**, *2*, 139-146.

S Virk, C-C L Kant, M Milosevic, D M Mravyan, B Grabovac, M Khodaei, C Chao, R Karkokli, R Li and K V McConville (2007), Improvement in balance with a cost-effective virtual reality environment, presented at *The 2007 FICCDAT - Festival of International Conferences on Caregiving, Disability, Aging and Technology*, Toronto.

W E Nordt 3rd, S A Sachatello, E S Plotkin and K Dintino (1999), The effects of single-axis balance board intervention on balance parameters in the elderly, *The American journal of orthopedics*, **28**, *8*, pp. 447-450.

W R Ferrell, N Tennant, R D Sturrock, L Ashton, G Creed, G Brydson and D Rafferty (2004), Amelioration of symptoms by enhancement of proprioception in patients with joint hypermobility syndrome, *Arthritis and Rheumatism*, **50**, *10*, pp. 3323-3328.

©2010 ICDVRAT; ISBN 978 07049 15022

Development of an interactive rehabilitation game using the Nintendo® WiiFit™ Balance Board for people with neurological injury

B S Lange[1], S M Flynn[1], C Y Chang[1], A Ahmed[2], Y Geng[2], K Utsav[2], M Xu[2], D Seok[2], S Cheng[2], A A Rizzo[1]

[1]Institute for Creative Technologies, University of Southern California, 12015 Waterfront Dr, Playa Del Rey, CA, USA

[2]Viterbi School of Engineering, University of Southern California, 3650 McClintock Ave, Los Angeles, USA

lange@ict.usc.edu, sherylflynn@yahoo.com, kchang@ict.usc.edu, abrar.here@gmail.com, gyx0576@gmail.com, arizzo@usc.edu

[1]www.ict.usc.edu, [2]www.viterbi.usc.edu

ABSTRACT

Visual biofeedback and force plate systems are often used for treatment of balance and mobility disorders following neurological injury. Conventional Physical Therapy techniques have been shown to improve balance, mobility and gait. The training program encourages patients to transfer weight onto the impaired limb in order to improve weight shift in standing and during gait. Researchers and therapists have been exploring the use of video game consoles such as the Nintendo® WiiFit™ as rehabilitation tools. Initial case studies have demonstrated that the use of video games has some promise for balance rehabilitation. However, initial usability studies and anecdotal evidence has indicated that the commercial games that are currently available are not necessarily suitable for the controlled, specific exercise required for therapy. Based on focus group data and observations with patients, a game has been developed to specifically target weight shift training using an open source game engine and the WiiFit balance board. The prototype underwent initial usability testing with a sample of four Physical Therapists and four patients with neurological injury or disease. Overall, feedback was positive and areas for improvement were identified. This preliminary research provides support for the development of a game that caters specifically to the key requirements of balance rehabilitation.

1. INTRODUCTION

Conventional Physical Therapy techniques have been shown to improve balance, mobility and gait following neurological injury. Visual biofeedback and force plate systems are used to assist treatment of balance and mobility disorders (Geiger et al., 2001; Walker et al., 2000; Yavuzer et al., 2006). The training programs encourage participants to shift weight onto the impaired limb in order to improve weight shift in standing and during gait. Visual feedback related to weight distribution and center-of-pressure positioning has been shown to be effective in increasing stance symmetry following stroke (Walker et al., 2000).

The use of the off-the-shelf video games as rehabilitation tools has gained much interest in the Physical Therapy arena over the past few years. However, limited published research exists on the feasibility and effectiveness of the use of this commercially available gaming system for rehabilitation. Researchers and therapists have been exploring the use of video game consoles like the Nintendo® WiiFit™ as rehabilitation tools. Initial case studies have demonstrated that the use of video games has some promise for balance rehabilitation. The published data presents case studies of patients who have survived stroke (Brown et al., 2009; Deutsch et al., 2009; Sugarman et al., 2009). These studies indicate that patients who used the Nintendo® WiiFit™ balance board and games demonstrated improvements in balance outcome measures. However more research is required with larger sample sizes and rigorous methodologies with comparison to standard treatment regimes.

Initial usability studies and anecdotal evidence has indicated that the commercial games that are currently available are not necessarily suitable for the controlled, targeted exercise required for therapy. Usability

©2010 ICDVRAT; ISBN 978 07049 15022

studies with patients who had survived Stroke, Spinal Cord Injury and Traumatic Brain Injury, have found that some commercially available games are providing negative auditory and visual feedback to patients that are performing tasks effectively because the patient cannot move fast enough for the game play or cannot perform all of the required movements within the game (Lange et al., 2009). When playing the Nintendo® WiiFit™, some patients who had difficulty with weight shift attempted to perform the game based task using sudden jerky movements. Feedback provided to patients following the game tends to be negative or inappropriate for the patient's level of ability (Lange et al., 2009).

The objective of this research was to design, develop and assess the usability of an interactive game specifically focused on training weight shift in a controlled and customized manner. The game was designed to be customizable and used by therapists to train patients with a range of levels of ability, using the Nintendo® WiiFit™ balance board. The use of a video game for balance training has the potential to increase motivational factors, collect quantitative data from the training session and customize the level of difficulty to each patient's specific needs.

2. METHODS

2.1 System Development

The game prototype was developed using Panda 3D game engine and can be played on PC using the Nintendo® WiiFit™ balance board as the interaction device. Findings from previous usability testing with Nintendo® WiiFit™ games, focus groups and clinical observations contributed to the design of a game that can be controlled by the therapist for speed, placement of cues on the screen, and the type and amount of visual, auditory and after action feedback. The balance board was chosen as the interaction device due to the increasing popularity of the Nintendo® WiiFit™ in rehabilitation, the low cost of the device and the potential for the device to be easily accessible to clinics and patients.

The balance board contains multiple sensors located on the bottom corners of balance board to measure and calculate center of pressure changes. Within the prototype, when the player moves their body on the balance board, rather than being transmitted to the Nintendo® Wii™ console, the data from the sensors is transmitted to a computer using Blue Tooth (Figure 1). The data consists of seven kinds of information: the weight from each of the four corners of the board, the total weight, and the x and y coordinates.

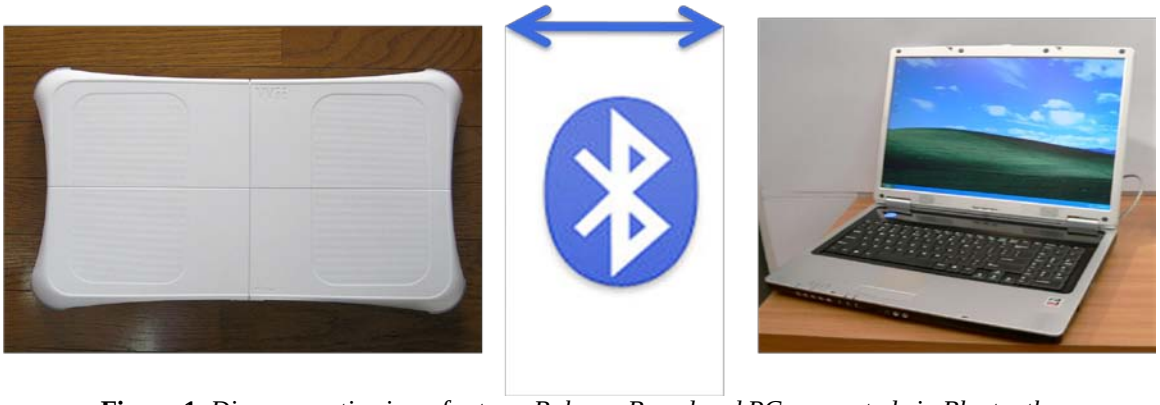


Figure 1. *Diagrammatic view of set up: Balance Board and PC connected via Bluetooth.*

The game prototype was developed using Panda3D. Panda 3D, developed by Disney and maintained by Carnegie Mellon University's Entertainment Technology Center, is a framework for rendering and game development using Python and C++ programs. Autodesk 3D Studio Max and Photoshop graphic tools were used to develop models and textures. 3D Studio Max is a comprehensive 3D modeling, rendering, and 3D animation software used by leaders in game development and film. OpenAL was used for audio effects. OpenAL is a cross-platform 3D audio API appropriate for use with gaming applications and many other types of audio applications.

Within the game, the player must navigate a balloon through a series of obstacles by shifting their weight on the balance board in the direction they want the balloon to move. These obstacles have been placed in such a way that the user has to shift weight from one leg to other in a controlled pattern. The ability to control the balloon within the anterior/posterior direction was initially disabled within the game. A user interface is

©2010 ICDVRAT; ISBN 978 07049 15022

currently being developed to allow therapists to make changes to the game controls, in order to make the game more accessible for patients of different levels of ability. For example, the therapist will have the ability to slow the flow of obstacles or change the pattern of obstacle flow in order to control the therapy session.

The game has undergone a number of iterations prior to testing with therapists and patients. Figure 2 presents a screenshot of the initial prototype of the game in which basic graphics were used whilst the team focused on improving the data capture and integration of the balance board into the system.

Figure 2. *Screen shot of first prototype of the game. The player must navigate the balloon through a series of obstacles by shifting their weight on the balance board in the direction they want the balloon to move.*

Following integration of the balance board data into the system, improvements were made to the graphics and gameplay elements. Figure 3 provides screenshots of simple and moderate game levels in which the obstacles the user must guide the balloon past are located at predictable and evenly spaced intervals (simple) or more unpredictable and random intervals (moderate).

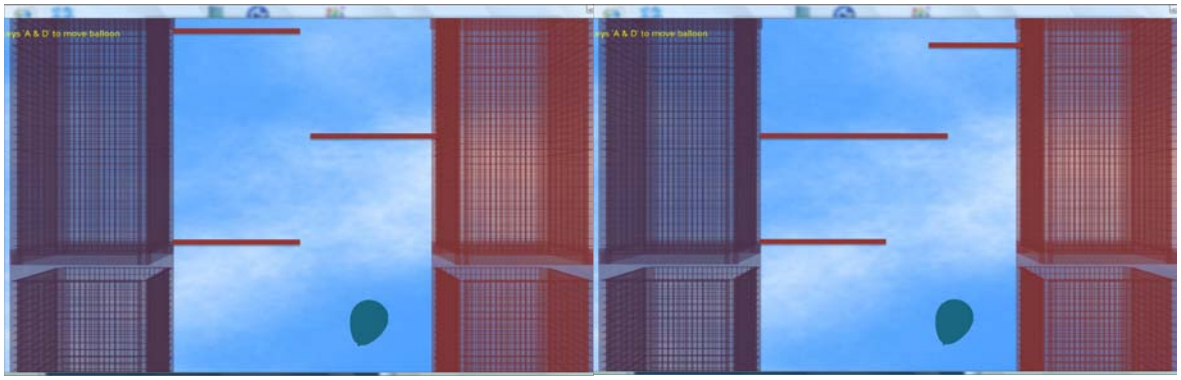


Figure 3. *Screenshot of second iteration of game with simple and moderate game levels.*

A more polished 3D version of the game was developed with realistic, professional graphics and music to provide a more 'game-like' experience (figure 3). Based on early user testing, the game was altered to include the collection of stars and the avoidance of other objects (rocks). The game has scoring for the number of objects you collect and the number of unwanted collisions with the rocks. The game has been designed so that different sounds are provided when the balloon connects with the stars and collides with the rocks. The balloon is not damaged if it collides with the rock, so as not to discourage patients whilst learning to play the game. However, in more challenging levels, the balloon will lose a small amount of size if it collides with a rock. This strategy aims to reduce the number of stop/start delays that occur during current commercial Nintendo® WiiFit™ games when the task is not achieved. Losing 'life' or failing the game as a result of limited ability to perform the task, therapist instruction or set-up delays can be frustrating and reduce patient confidence, motivation and compliance. The current prototype aims to improve upon these negative features, providing the patient with support, positive reinforcement and graded challenge levels.

©2010 ICDVRAT; ISBN 978 07049 15022

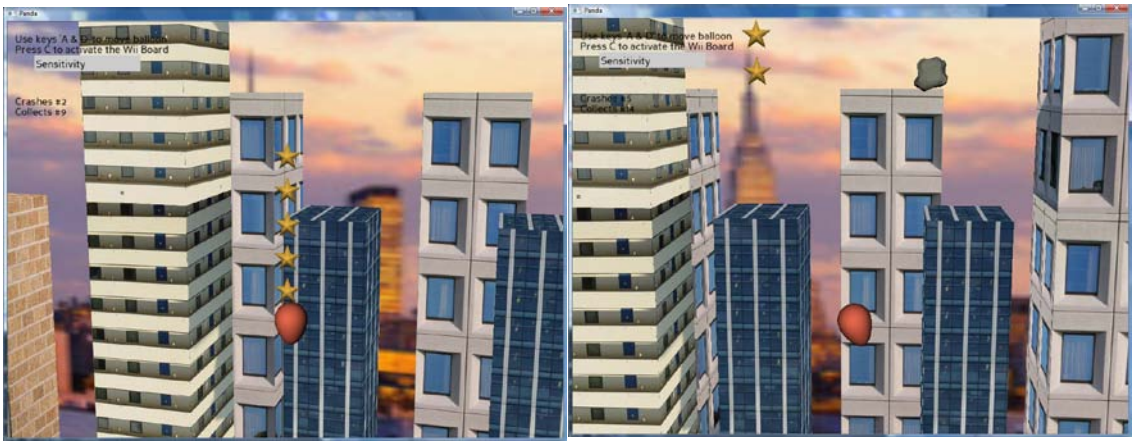


Figure 4. *Screenshot of third iteration of game with 3D graphics and objects.*

The system has undergone preliminary assessment within the research team to assess the features of the game prior to use with the intended patient population. Preliminary assessment with a sample of nine able-bodied participants aged 23 to 41 years provided ideas for scoring, timing and other game play activities that were incorporated into the current game prototype.

2.2 Initial Assessment of System

A sample of Physical Therapists and patients with neurological injury or disease were recruited from Precision Rehabilitation, a private outpatient neurological Physical Therapy clinic in Long Beach, CA. Therapists and participants with neurological injury were asked to play the game prototype within a safe clinical setting, with assistance if required. All participants played the 3D version of the game set at a standard difficulty level. All patients wore gait belts and were provided with the opportunity to use a frame if required. Participants were asked to comment on their experience through a semi-structured interview consisting of open-ended questions. The researchers also manually recorded observations of the interaction. When possible, if a patient's therapist was present during the testing, the therapist was also asked to comment on the interaction, system and game play. Both therapist and patient groups were asked to provide suggestions for improvements to the game play and system set-up.

3. RESULTS

3.1 Sample

To date, four Physical Therapists (two experienced clinicians and two novice 3rd year student clinicians) and four patients have been recruited. Two participants survived stroke at least one month prior to testing (one male and one female). Two males with a spinal cord injury, one was four months post injury and one was two years post injury and one female with ALS who was diagnosed 1.5 years ago were also recruited.

3.2 Patient Feedback

All patients were able to step up onto the balance board with assistance from the researchers. Two patients used a walker during the task. One patient had stand-by assist and three patients had light-to moderate assistance using the gait belt. All patients were able to play the game and achieve the game play tasks. Three patients reported enjoying playing the game. One patient reported that she did not enjoy the experience and the game was confusing. However this patient was able to score well within the game and complete all required gameplay without any obvious difficulties. All patients required a small learning period to adjust to the use of the balance board. Three patients reported that playing the game helped them to shift their weight more than they would during other exercises they do. Two patients had previously used the Nintendo® WiiFit™ balance board and commercial Nintendo® WiiFit™ games. These patients were asked how their experience with the prototype compared to the commercially available console games. One patient responded "*even though [the prototype game] was pretty challenging, it was easier to play than some of the other [Nintendo® WiiFit™] games that need you to have really good control and fast movements*". The other patient responded "*I haven't played the other [Nintendo® WiiFit™] games since my injury but I'm pretty sure I wouldn't be as good at them as I was at this game*".

©2010 ICDVRAT; ISBN 978 07049 15022

Some other comments made by patients about their experience are listed below:

"It took me a little bit to figure it out but after that it was fun"

"It gave me confidence to stand on one foot. I haven't done that in a while"

"It was hard work but I enjoyed it"

"It was a distraction. If you told me to shift my weight like that without playing a game, I would be really scared and I probably wouldn't do it but when it was in a game, I didn't really think about how scary it was. I had a goal and I just went for it"

"I had to really work hard but it was good"

"I worked harder than I would have in normal therapy and I could see myself doing it for longer if I played this rather than having to do one of the exercises I normally do in the bars"

"I would stand up more often if this game was here in the clinic all the time"

Researchers observed that patients took approximately four-seven weight shifts to adjust to the game. Patients made full weight shifts between right and left when required by the game. Maximum number of collisions with the rock objects was three and minimum number of star objects collected was 100, indicating that the patients were all successful in performing the required in-game tasks. Some difficulties were observed with maintenance of the patient's foot position within an ideal location on the balance board. One therapist suggested the use of a block between the patient's feet to reduce movement. This was trialed successfully with two of the patients, indicating the need for a more secure, yet flexible balance board set-up.

3.3 Therapist Feedback

All therapists were able to use the balance board device to interact with the game appropriately. Therapists commented that they enjoyed playing the game and they thought the game would be appropriate and useful for a number of their patients. The two therapists that worked with patients during the testing said they were impressed by the amount of focus and weight shift the patients had whilst playing the game. Both commented, without prompting, that they had not seen their patients transfer as much weight onto their impaired limb during other tasks. The therapists were enthusiastic about further use of a game like this with their patients in the future

Three therapists were asked to play two levels of difficulty of the 2D version of the game in addition to the 3D version of the game. Two therapists commented that they like the 2D version for patients because it was simpler and had a less distracting background. Therapists provided useful feedback and suggestions about how to improve gameplay in a way that would focus on specific therapy tasks.

Some comments from therapists include:

"This has great potential for our patients"

"I think [my patient] really enjoyed playing the game. She did really well too! She doesn't normally stand on her [impaired] leg"

"I think you could do a lot of different things with this, there are a lot of options for functional tasks to be incorporated and it would be great to have anterior/posterior movement as well"

"I like the 2D version better. The background is simpler and I think it would be better for some patients with cognitive impairments"

"I like that you can vary it like that, it's cool"

"It took a minute or so to get used to the sensitivity of the board…. But after I got used to it, it was fine"

"I feel like this will give some of my patients a sense of achievement during their therapy"

"It could help some of my patients to get the feel of weight transfer"

"I can see this being a very useful training tool"

Researchers observed that therapists took approximately two or three weight shifts to adjust to the game. Therapists did not need assistance to perform the task. Maximum number of collisions with the rock objects was 2 and minimum number of star objects collected was 140, indicating that the therapists were all

©2010 ICDVRAT; ISBN 978 07049 15022

successful in performing the required in-game tasks.

3.4 Planned enhancements and improvements

Based upon the suggestions from the participants, further enhancements of the balance board set-up include the design of a platform and alterations in sensitivity of the pressure sensor measurement. Software improvements include enhanced clinician user-interface menu and alteration of the game play elements to provide more varied interaction.

4. CONCLUSIONS

A game was developed to specifically train weight shift and improve balance in patients using a Nintendo® WiiFit™ balance board. Initial assessment of the prototype with a sample of Physical Therapists and patients with neurological injury demonstrated that the use of this prototype has potential as a rehabilitation tool. Clinicians and patients provided valuable input and have identified a number of refinements and improvements to the system. Future directions in this research will be further usability testing followed by a larger feasibility trial to determine if the use of the game as a training tool improves balance outcomes.

Acknowledgements: The team would like to thank the participants from Precision Rehabilitation in Long Beach for their time, enthusiasm and feedback. The authors would also like to thank Jamie Antonisse for his game design expertise and Rachel Proffitt for her input, support and help with data collection. This work was supported by NIDRR through the OPTT RERC at the University of Southern California.

5. REFERENCES

J E Deutsch, D Robbins, J Morrison, P G Bowlby (2009), Wii-based compared to standard of care balance and mobility rehabilitation for two individuals post-stroke. *IEEE: Virtual Rehabilitation International Conference*. Haifa pp 117-120.

R A Geiger, J B Allen, J O'Keefe, R R Hicks (2001), Balance and Mobility Following Stroke: Effects of Physical Therapy Interventions With and Without Biofeedback/Forceplate Training. *Phys Ther*. 81(4). pp 995-1005.

B S Lange, S M Flynn, A A Rizzo (2009), Initial usability assessment of off-the-shelf video game consoles for clinical game-based motor rehabilitation. *Physical Therapy Reviews*.14 (5) pp 355-363.

H Sugarman, A Weisel-Eichler, A Burstin, R Brown (2009), Use of the Wii Fit system for the treatment of balance problems in the elderly: A feasibility study. *IEEE: Virtual Rehabilitation International Conference*. Haifa pp111-116.

C Walker, B J Brouwer, E G Culham (2000), Use of Visual Feedback in Retraining Balance Following Acute Stroke. *Phys Ther*. 80(9). pp 886-895.

G Yavuzer, F Eser, D Karakus, B Karaoglan, H J Stam (2006), The effects of balance training on gait late after stroke: a randomized controlled trial. *Clinical Rehabilitation*. 20(11). pp 960-969.

©2010 ICDVRAT; ISBN 978 07049 15022

Development of a voice-based rhythm game for training speech motor skills of children with speech disorders

D Umanski[1], D Kogovšek[2], M Ozbič[2], N O Schiller[1]

[1]Leiden University Centre for Linguistics, Leiden Institute for Brain and Cognition (LIBC), Leiden University, THE NETHERLANDS

[2]Department of Speech Therapy and Special Education, Faculty of Education, University of Ljubljana, SLOVENIA

daniil.umanski@gmail.com

ABSTRACT

In this project, we deal with the development and evaluation of a new tool for conducting speech rhythm exercises. A training methodology is proposed, based on a schedule of exercises, each presenting a sequence of syllables arranged in a specific rhythmic pattern. In order to assist the therapists with conducting speech rhythm exercises with children, we have developed a computer game prototype which implements the training, by providing the exercises, visual feedback and evaluation of performance. The game prototype was further evaluated in a usability study involving children with various speech disorders. We discuss the limitations of the current system and propose improvements for further development.

1. PRINCIPLES OF SPEECH MOTOR PRACTICE

1.1 Speech rhythm skills

Recent studies have argued for the presence of a central timing deficit in children with speech disorders, expressed across modalities and across types of timing measures (Peter and Stoel-Gammon, 2008). Particularly, a problem with timing accuracy in speech is thought to be implicated in childhood apraxia of speech (CAS), and in dysarthria (Liss et al, 2009), conditions jointly known as speech motor disorders (Duffy, 2005). Fluency disorders have also been extensively studied from the speech motor skill perspective (Van Lieshout, 2001).

Since speech motor skills involve an intricate timing and coordination of motor events, we can describe speech rhythm skill as one of the elements comprising it. Concretely, speech rhythm skill can be defined as the ability to reproduce consecutive speech segments with a precise onset and offset timing of each segment.

1.2 Motor Learning

The work-frame of motor skill learning indicates that repeated mass practice, provided with appropriate tasks, goals, schedule and feedback, results in consolidated skills (Maas et al, 2008). As a direct consequence, it can be expected that the refinement of speech rhythm skills by means of repeated practice would lead to improved speech motor skills, and therefore empower people with speech disorders to make progress in their treatment. An insightful design of speech motor training exercises is warranted in order to achieve an optimal learning process, in terms of efficiency, retention, and transfer levels (Namasivayam and Van Lieshout, 2008).

1.3 Speech motor practice

It is now generally agreed that speech motor exercises should involve simplified speech tasks. The use of non-sense syllable combinations is a generally accepted method for minimizing the effects of higher-order linguistic processing levels (Smits-Bandstra et al, 2006). Therefore, our training methodology consists of a schedule of exercises, each presenting a sequence of syllables arranged in a specific rhythmic pattern. This is somewhat similar to a form of jazz-singing known as 'scat-singing' (see Figure 1 for an example). Further, the training schedule is designed, in which speech items are selected and the rhythmic complexity of the

©2010 ICDVRAT; ISBN 978 07049 15022

exercises is manipulated according to speci fic principles (Maas et al, 2008).

One important principle in the design of exercises is the selection of speech items, as it has been shown that manipulating syllable sets for speech training has an affect on motor learning (Staiger and Ziegler, 2008). In an effort to accommodate this insight into our training methodology, we have constructed, in previous work, an interface for clinicians for selecting speech items based on individual articulatory needs of their patients (Umanski et al, 2010). This application allows to produce lists of syllables which can be directly utilized as speech material in speech rhythm exercises.

1.4 Current rhythm skills training system

A new genre of rhythm video games has recently emerged. In those games, players must press buttons at a precise time corresponding to a sequence dictated by the game. Doing so will cause the game's protagonist to dance or play their instrument correctly, thus achieving a greater score. Although commercial rhythm games often feature novel input devices, no voice-based games have so far been conceived and applied for training speech rhythm skills. Therefore, in this project we aim to construct a practical tool which will provide the appropriate conditions for learning and training of speech rhythm skills.

Figure 1: *Louis Armstrong's 'Heebies Jeebies' (1925)*

2. DEVELOPMENT OF A SPEECH TRAINING SYSTEM

2.1 A speech rhythm game

In order to experiment with the methodology of speech rhythm exercises, we have built a first prototype of a speech rhythm game. The theme of this game is a downhill slalom ski competition. The player uses microphone input to control the movement of a slalom skier, so that each syllable onset causes the skier to change direction on his way down the piste. The goal of the player is to produce a sequence of syllables with precise timing, so that each syllable onset corresponds with taking a well-timed turn at a flag.

Each exercise is realized in the game by positioning the flags in such a manner that their relative distances faithfully represent the rhythmic pattern to be practiced. In other words, the spatial distance between flag *i* and flag *i*+1 corresponds to the temporal note duration of element *i* in the exercise. Such spatial correspondence provides the basis for predictive feedforward control, which has been shown to support the motor initiation of rhythmic productions (Zatorre et al, 2007). Each flag is further labeled with the syllable which needs to be produced at that specfic moment in the exercise. For the sake of visual clarity, the exact points of expected syllable onsets are marked with a cross. The game follows the 'call and response' format, in which the correct rhythmic pattern is first demonstrated by means of animating the skier to perform an 'optimal' slalom ride, synchronized with an audio playback1 of the given rhythm. The player is then prompted to perform the exercise.

2.2 Adaptability

In the case when a player produces an inaccurate interval, the game will dynamically adapt the motion of the skier in order to sustain the synchrony between the next expected note duration and the visual representation of that interval. For example, if the onset is produced later than the expected moment, the trajectory of the skier towards the next flag will be animated in such a way that the skier will arrive at the next flag exactly within the next expected interval. This way, the player is not 'punished' for less then precise productions, and has a better chance to synchronize back to the correct rhythm after going 'out of sync'. Furthermore, the clinician can set the appropriate speed for a child, so that both the rhythmic pattern and the motion of the skier are scaled in time. Reducing the risk of frustration, and keeping the player at an optimal challenge level is meant to maintain motivation and flow during gameplay.

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

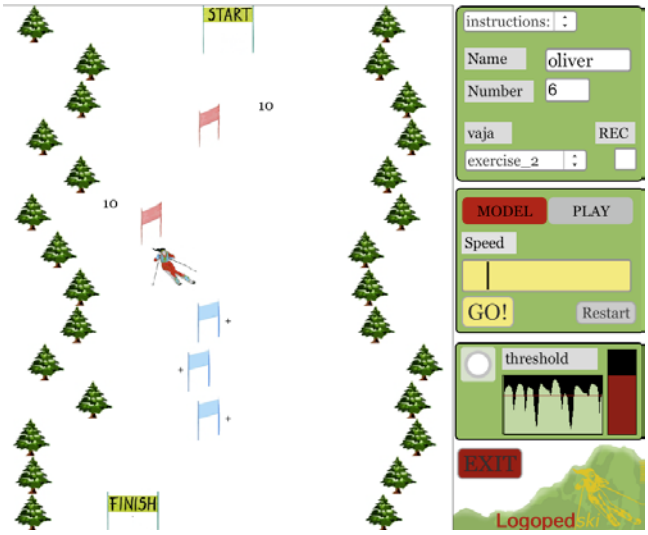


Figure 2: *A screenshot from the rhythm game prototype*

2.3 Evaluation and feedback

In order to evaluate the rhythmic pattern produced by the player in relation to the given exercise, we detect syllable onsets and calculate the inter-onset-intervals (IOI). Each interval is compared with the expected note duration for that specific syllable, and their absolute difference is obtained. The evaluation occurs in real-time, so that immediate visual feedback indicates whether the current syllable onset has been produced with accurate timing. The summing up of individual interval deviations results in an overall score for the exercise and is stored for further evaluation and progress monitoring.

2.4 Creating speech rhythm exercises

In order to offer clinicians a modular way of creating individual exercises for their patients, we have built an interface which allows the compilation of custom rhythmic sequences. The interface, illustrated in Figure 3, includes a graphic representation of note durations associated with each syllable in the exercise. As the clinician selects a sequence of note durations for a certain exercise, a graphical representation of the exercise is updated. When the exercise is compiled, it can be saved to a file, and the process repeated as long as necessary. The created exercises are automatically added to the exercise-menu of the game.

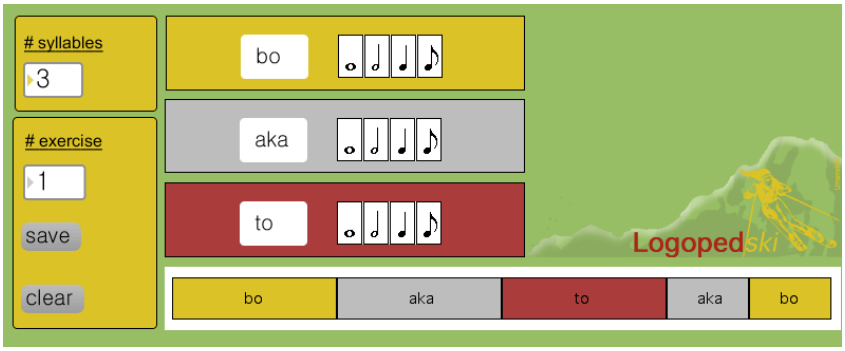


Figure 3: *A screenshot from the rhythm exercise- making interface*

2.5 Implementation

The main technical challenge in our development is the task of syllable onset detection in real-time. Because the phonetic realization of co-articulated syllables tends to blur the acoustic markers of syllable boundaries, the task of detecting each syllable becomes far from trivial. For example, semivowels are produced without complete closure of the vocal tract or frication, and have similar spectral characteristics with vowels. Therefore, a syllable such as /la/ would be difficult to distinguish from its preceding syllable. A similar problem arises with nasal consonants, such as /n/ and /m/. In general, the speech signal does not allow for a

©2010 ICDVRAT; ISBN 978 07049 15022

straightforward detection of boundaries when speech is continuous.

Most research in the area of automatic onset detection focuses on real-time onset detection of musical events per se. On the other hand, the studies which investigated syllable nuclei or syllable boundary detection in speech rely on large analysis windows (around 800 ms), and are therefore not appropriate for real-time implementation (Kochanski and Orphanidou, 2008).

2.5.1 Onset detection function. In the technical literature, there are two main approaches to the onset detection task. The most straightforward detection function is based on the energy of the signal, which is associated with perceived loudness. A logarithmic energy function is considered more psycho-acoustically relevant (Klapuri, 1999). In our exercises, energy rising above a specific threshold corresponds to syllable nuclei, and therefore allows us to track the rhythmical pattern of consecutive syllables. While this function works well for separated syllables, it runs into trouble with some of the syllables produced in coarticulation, as discussed above.

Another approach is a detection function based on spectral difference, which is defined as the sum of the spectral bin magnitude differences between adjacent audio frames (Kumar et al, 2007). This function is more sensitive to variations on the phoneme level, but tends to produce more 'false onsets'. The application of this function demands a smoothing of the difference signal, and the amount of smoothing strongly affects the detection robustness. In general, both detection functions require parameters settings in order to achieve reasonable performance, and no universal settings, in terms of smoothing factors or thresholds, can be readily set up. We have experimented with both detection functions, which exhibited similar performance once parameters are manually set. We have then concluded that the energy threshold function is more appropriate to be used in the current application, since setting for energy threshold is more transparent (in terms of human-computer-interface and the user group in mind) than tweaking smoothing factors in the spectral difference function.

2.5.2 Manual parameters settings. With these considerations in mind, we have included a manual setting of the noise floor and the onset threshold levels in the interface of the game (see Figure 4). The task of the clinician is to set the appropriate levels in accordance to the acoustic situation of the training - the noise floor level according to the static noise in the room where the exercises take place, and the onset threshold according to the voice of the specific child. An indicator is added in the interface (top left corner in Figure 4), which lights up when the signal energy threshold is passed, so that the clinician can visually verify the detection function on produced syllables. Integrating these manual settings into the game reflects a somewhat problematic tradeoff inherent in all systems, which rely on microphone input in an unpredictable environment. On the one hand, for optimal usability, the system should require as least manual settings as possible, and try to adjust its internal settings automatically. On the other hand, if internal settings are not optimally set for a specific situation, the system robustness and reliability would be compromised.

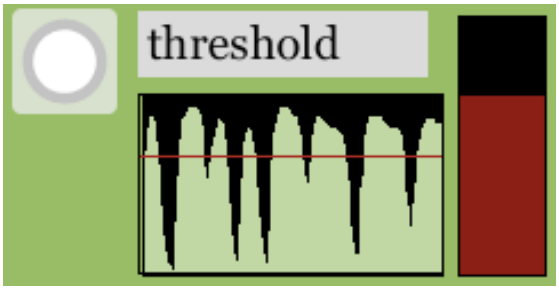


Figure 4: *Manual threshold setting*

2.5.3 Potential system improvements. One possibility in advancing the detection function is to consider a multimodal setup, in which visual input from the player is integrated with the audio input to produce better predictions of onsets. Furthermore, a learning mechanism can be employed, which learns to map acoustic features of individual players to onset detection events. In this scenario, the clinician might provide external cues to the system in the learning phase, in which appropriate mappings are stored.

©2010 ICDVRAT; ISBN 978 07049 15022

3. USABILITY STUDY WITH THE RHYTHM GAME PROTOTYPE

3.1 Study goals

We have conducted an initial study to access the usability of the current prototype of the speech rhythm game. The study was performed in the School for the Deaf and Hard of Hearing in Ljubljana, Slovenia (http://www.zgnl.si). The clinicians of the school provide speech therapy not only to hard of hearing children, but also work with ambulatory patients with a wide variety of speech and language disorders, including stuttering, speech motor disorders, phonology and articulation disorders. The goal of the study was to perform an initial evaluation of the suitability of a speech rhythm game as a valuable tool for speech therapist's work. In addition, we wished to collect the impressions of clinicians as to which target groups of children the proposed game could eventually target, in terms of diagnosed speech disorders and age.

3.2 Procedure

During the study period of six weeks, clinicians used the game to practice speech rhythm skills with patients for whom such training made sense from the therapy program point of view. The guideline for the clinicians was to perform the training with children having various disorders and various ages in order to get a better overall impression on the usability aspects of the system. At the end of the evaluation period, clinicians were presented with a questionnaire which included 10 items aiming at evaluating various aspects of the training experience. The questionnaire was adapted from Öster (2006) for evaluating the usability of the 'Box of Tricks' software. For each item, the clinicians chose the most appropriate answer on a 4-point scale, and added their own comments on that question, where appropriate. In total, 6 clinicians, having worked with 26 children have completed the study period. Each child completed 2-4 practice session with the game, on separate occasions, each lasting for 10-15 minutes. During each practice session, the clinicians were free to choose the rhythmical exercises which best fit to the level of the child, as well as the syllables, which are to be produced, in accordance with the child's abilities.

3.3 Subjects

The group of children included 7 girls and 19 boys, aged 4-10, with an average age of 6.6 years. Among these children, 9 have articulation problems, 7 stutter, 7 have an expressive language disorder, 2 children are hard of hearing, one is diagnosed with Asperger's syndrome, and one has a cleft palate (among these subjects, a few children are diagnosed with multiple disorders).

3.4 Results and discussion

In this section, we report and discuss the experiences and impressions expressed by the clinicians in relation to each of the items in the usability questionnaire (see Figure 4 on the next page for charted results):

1) Concerning previous computer knowledge required for using the game, the replies suggest that among the clinicians who participated, this issue presented no obstacle. Additionally, an interesting insight comes from the following fact: Initially, eight therapists engaged in the usability study. However, two have stopped shortly after, as a result of being uncomfortable with using a computer-based system. These two therapists are the eldest in the team, and their lack of comfort with using the computer is an important factor for consideration. Development of software for speech clinicians as the target group might need to face the choice between applying specific usability principles for the 'technology-intolerant' sub-group, such as older generations of clinicians, or targeting the younger generations of clinicians per se.

2) The question whether children understood the visual feedback provided by the game remains inconclusive. Clinicians report that while children understood that they have to 'say sounds' in order to make the skier turn, as well as the changing of the colors of the flags, some did not understand the point of the numbers presented on the screen. It might be the case that for the younger children, presenting the score in a numerical form is too complex, and a more simplified visualization scheme is needed.

3) Concerning the motivation of children to practice with the game, the clinicians report, rather unanimously, that children were motivated to practice only during the first few attempts, and their enthusiasm faded after a few trials. This is not surprising if considering the importance of variation in game design and the rather static nature of the current game prototype, which features one screen only. For children who regularly play modern computer games, the current setup is not able to satisfy the variation standards they are used to. In future work, we will need to provide a game environment which optimally preserves the flow of game-play, by including variable graphical themes, while controlling for adaptable levels of challenge.

©2010 ICDVRAT; ISBN 978 07049 15022

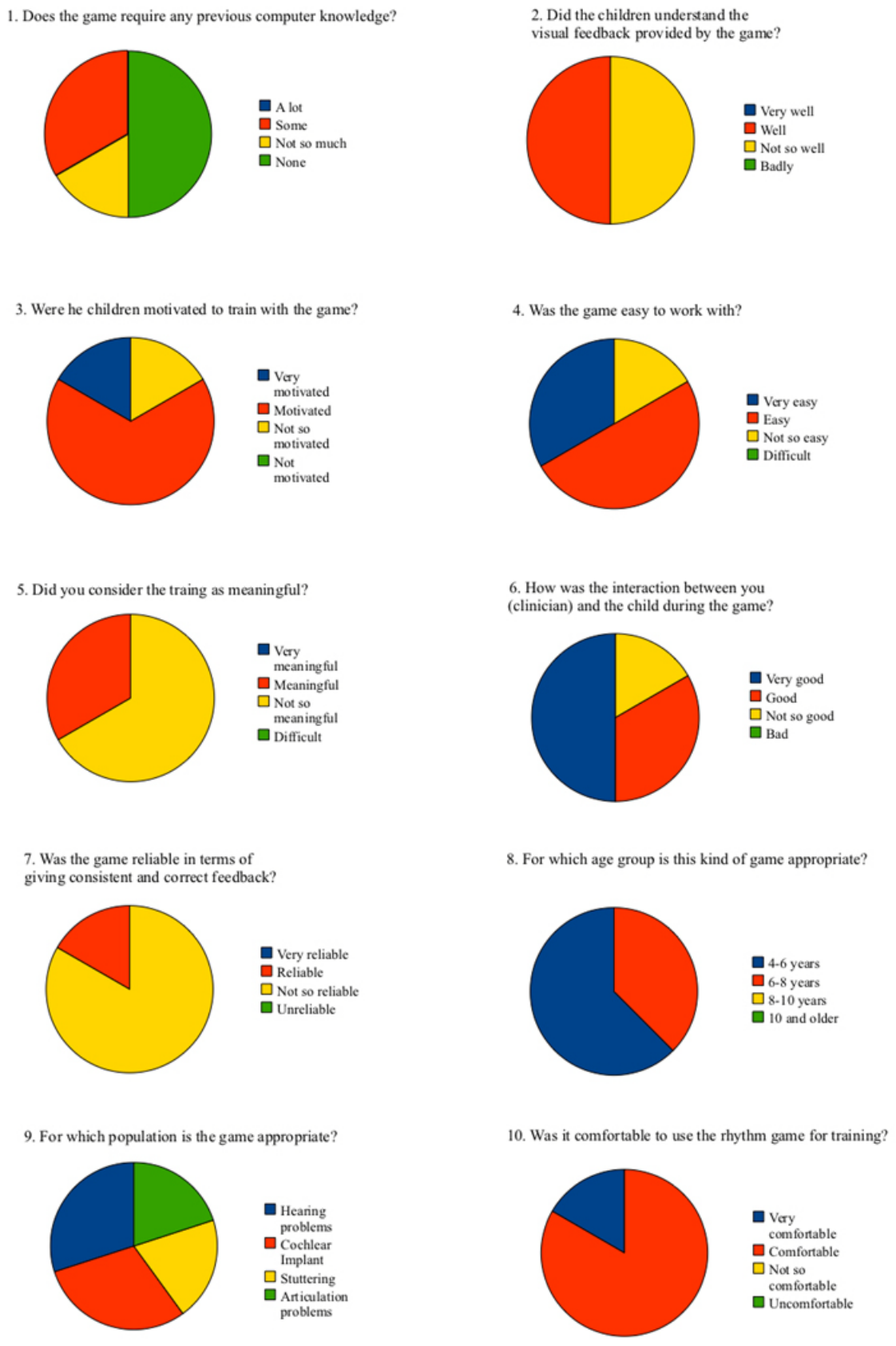


Figure 5. *Results of the usability questionnaire.*

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

4) As for the game being easy to use for training, although clinicians tend to regard it as being generally so, they do report difficulties with using the manual controls for noise floor level and for the syllable onset detection. This difficulty is understandable, and reflects the inherent tradeoff between the amount of manual settings and system robustness in microphone based applications (as discussed in the 'Implementation' section). This problem demands a special attention when designing applications for speech therapists, as any mechanism less than intuitive could compromise the usability of the system.

5) For the question of the speech rhythm training being meaningful, no clear conclusion was derived. As a critic, one clinician mentioned that other speech skills than rhythm can better be trained with the game, meaning that rhythm per se is not the main element which the children focused on. Another clinician reported that there were too many different rhythms with little difference between them. The lack of graphical variation has also been reported as diminishing the meaningfulness of the training, probably due to its influence on the motivation to practice.

6) The interaction between the child and the clinician during practice have been positively regarded. Clinicians mentioned that children were willing to cooperate with them in the process of playing the game, and that children were ready to listen to instructions and guidelines while playing. Only one clinician reported some children being more occupied with the game than listening to her.

7) The reliability of the game in terms of providing consistent feedback has been observed as not enough reliable. Clinicians report that consistent feedback depends on the manual noise and threshold settings, as well as on the speech items being produced. These observations confirm our discussion in section 'Implementation', where the robustness issues of syllable onset detection are discussed. It is clear therefore, that future versions of the speech rhythm game must include a more robust mechanism of detecting beats in the speech signal.

8) As for the age group most suitable for using the speech rhythm game, clinicians seem to agree that 4-6 years old can best appreciate this form of training. Children who are 6-8 years old are also found to be involved with the game, but to a lesser degree.

9) Concerning the target populations for whom a speech rhythm training is beneficial, clinicians mentioned all the disorders found in the group of children involved in the study. Mostly, articulation problems and hearing problems were pointed out, although stuttering and children with cochlear implants are also believed to gain from this training.

4. CONCLUSIONS

In this paper, we have presented a new method for conducting speech rhythm exercises. The theoretical background and the clinical motivation for developing a computer-based intervention for speech rhythm training were outlined and discussed. We have then described a game prototype which aims to implement the proposed methodology. The speech rhythm game provides a training platform in which each exercise is visually presented, and the rhythmical pattern needs to be matched by the player through producing syllable sequences in accurate timing. The mechanisms of the game prototype have been detailed, which allow for adaptability, evaluation of performance, visual feedback and score presentation. Furthermore, a special interface which allows clinicians to create speech rhythm exercises has been described. The system implementation revolves around the non trivial task of detecting syllable onsets in real-time. The difficulties and approaches to this task have been suggested.

In order to evaluate the usefulness of the proposed approach and the current game prototype, a usability study was conducted. During this study, clinicians have been using the speech rhythm game with children diagnosed with a variety of speech disorders. In general, clinicians report to have been comfortable with using the speech rhythm game for training with children. They have voiced a number of significant critics on the current prototype of the game. The main limitations at this point seem to be the lack of robustness on detecting syllable onsets, and the lack of graphical variation during game-play. While graphical variation is a matter of extension and elaboration, the problem of robust onset detection will require extensive development, as the state of the art techniques in this field do not yet offer a satisfying solution.

In spite of outlining a number of critics on the usability of the current game prototype, clinicians have expressed a positive attitude towards this line of development. They have concluded that although the game prototype requires improvement, the initiative is very welcome, and further prototypes will be anticipated. The outcomes of the usability study have equipped us with a deeper understanding of the challenges and

©2010 ICDVRAT; ISBN 978 07049 15022

difficulties involved in developing this method of training, but also of its potentials. We will be concerned with advancing this development further on.

Acknowledgements: This research is supported with the 'Mosaic' grant from The Netherlands Organisation for Scientific Research (NWO). The authors are grateful for the anonymous reviewers for their constructive feedback.

5. REFERENCES

J R Duffy (2005), Motor speech disorders: Substrates, Differential Diagnosis, and Management, *(2nd Ed.) 507-524. St. Louis, MO: Elsevier Mosby.*

A Klapuri (1999), Sound onset detection by applying psychoacoustics knowledge, *in Proc. IEEE Intl. Conf. on Acoustics, Speech, and Signal Processing, Arizona, pp. 3089-3092.*

G Kochanski, C Orphanidou (2008), What marks the beat of speech? *J. Acoustical Society of America 123, 2780–2791.*

J M Liss, L White, S L Mattys, K Lansford, A J Lotto, S M Spitzer, J Caviness (2009), Quantifying speech rhythm abnormalities in the dysarthrias, *Journal of Speech, Language, and Hearing Research Vol. 52 1334–1352.*

E Maas, D A Robin, S N Austermann Hula, S E Freedman, G Wulf, K J Ballard, R A Schmidt (2008), Principles of Motor Learning in Treatment of Motor Speech Disorders, *American Journal of Speech-Language Pathology, 17, 277-298.*

A K Namasivayam, P Van Lieshout (2008), Investigating speech motor practice and learning in people who stutter, *Journal of Fluency Disorders 33 (2008) 3251.*

A M Oster (1996), Clinical applications of computer-based speech training for children with hearing impairment, *Proc. ICSPL 1996, 157-160. Philadelphia, USA.*

B Peter, C Stoel-Gammon (2008), Central timing deficits in subtypes of primary speech disorders, *Clinical Linguistics & Phonetics, 22(3): 171–198.*

P Pradeep Kumar, P Rao, S Dutta Roy (2007), Note Onset Detection in Natural Humming. *iccima, vol. 4, pp.176-180, International Conference on Computational Intelligence and Multimedia Applications (ICCIMA 2007).*

S Smits-Bandstra, L F DeNil, J Saint-Cyr (2006), Speech and non-speech sequence skill learning in adults who stutter, *Journal of Fluency Disorders, 31,116136.*

A Staiger, W Ziegler (2008), Syllable frequency and syllable structure in the spontaneous speech production of patients with apraxia of speech, *Aphasiology, Volume 22, Number 11, November 2008 , pp. 1201-1215(15).*

D Umanski, F Sangati, N O Schiller (2010), How spoken language corpora can refine current speech motor training methodologies, *Proc. ACL2010 Intl. Conf..*

P Van Lieshout (2001), Recent developments in studies of speech motor control in stuttering, *In B. Maassen, W. Hulstijn, R. D. Kent, H. F. M. Peters, P. H. H. M. Van Lieshout (Eds.), Speech motor control in normal and disordered speech (pp. 286290). Nijmegen, The Netherlands:Vantilt.*

R J Zatorre, J L Chen, V B Penhune (2007), When the brain plays music: auditory-motor interactions in music perception and production, *Nature Reviews Neuroscience 8, 547-558.*

©2010 ICDVRAT; ISBN 978 07049 15022

Robotic vocalization training system for the auditory-impaired

M Kitani, T Hara, H Hanada, H Sawada

Department of Intelligent Mechanical Systems Engineering, Faculty of Engineering,
Kagawa University, 2217-20, Hayashi-cho, Takamatsu-city, Kagawa, 761-0369, JAPAN

s10d501@stmail.eng.kagawa-u.ac.jp, sawada@eng.kagawa-u.ac.jp

http://www.eng.kagawa-u.ac.jp/~sawada/index_e.html

ABSTRACT

The authors are developing a vocalization training system for the auditory-impaired using a talking robot. The training system mainly consists of a talking robot which has mechanical organs like a human. With an adaptive learning strategy using an auditory feedback control, the robot autonomously learns the vocalization, and then reproduces the speech articulation from inputted sounds. By employing the talking robot, the training is realized by two different approaches. One is a training based on the hardware demonstration, which shows the speech articulation by the robotic motions, and the other is a software-based training, which shows the phonetic characteristics of generated voices. Training experiments are being conducted in Kagawa Prefectural School for the Deaf, and significant results have been obtained. In the previous system, the speech learning algorithm of the robot was constructed by using a Self-organizing Neural Network (SONN), which consists of the combination of a Self-organizing Map (SOM) and a Neural Network (NN). However, improper maps were found in the results of the speech articulation learning. In this study, a new algorithm using two SOMs, called a dual-SOM, is introduced for the autonomous learning of the robotic articulations. Firstly, the construction of the training system is described together with the autonomous learning of robotic vocalization using the dual-SOM algorithm, and then the analysis of the speech training progress is presented based on the phoneme characteristics and the mechanical vocal articulations.

1. INTRODUCTION

A voice is the most important and effective method of verbal and nonverbal communications. Various vocal sounds are generated by the complex articulations of vocal organs such as lung, trachea, vocal cords, vocal tract, tongue and muscles. The airflow from the lung causes the vocal cords vibration and generates a source sound, then the sound is led to a vocal tract to work as a sound filter as to form the spectrum envelope of a particular sound. The voice is at the same time transmitted to the human auditory system so that the vocal system is controlled for the stable vocalization.

Infants have the vocal organs congenitally, however they cannot utter a word. As infants grow they acquire the control methods pertaining to the vocal organs for appropriate vocalization. These get developed in infancy by repetition of trials and errors concerning the hearing and vocalizing of vocal sounds. Any disability or injury to any part of the vocal organs or to the auditory system might cause an impediment in vocalization. People who have congenitally hearing impairments have difficulties in learning vocalization, since they are not able to listen to their own voice.

Auditory impaired patients usually receive a speech training conducted by speech therapists (STs) (Boothroyd, 1988; Boothroyd 1973; Erber et al, 1978; Goldstein & Stark, 1976), however many problems and difficulties are reported. For example, in the training, a patient is not able to observe his own vocal tract, nor the complex articulations of vocal organs in the mouth, and he cannot recognize the validity of his speech articulations nor evaluate the achievement of speech training without hearing the voices. Children regularly take training in a deaf school during a semester, however it is not easy to continue the training during school holidays, and they tend to forget the skills, so that they resume the training again in the beginning of the new semester by repeating the previously-conducted training menus. The most serious problem is that the number of STs is not enough to give speech training to all the patients with auditory impairment. A simple training system or a supporting device that a patient regularly uses for daily speech training by oneself is strongly required.

©2010 ICDVRAT; ISBN 978 07049 15022

2. VOCALIZATION TRAINING AND THE RELATED STUDIES

Figure 1 shows two examples of electronic speech training systems, WH-9500 developed by Matsushita Electric Industrial Co., Ltd., and JX-1 developed by Body sonic Co., Ltd. Equipped with a headset with a microphone, WH-9600 directs the difference of sound features together with an estimated vocal tract shape on the display, so that a trainee could understand his own vocalization visually. The system is large and requires technical knowledge and complex settings, and it is difficult for an individual patient to settle it at home. JX-1, on the other hand, consists of two vibration units, one for hands and the other for a body. The trainee inputs a voice to the system via a microphone, and the system presents the phonetic difference between the able-bodied voice and the trainee voice by vibration patterns. It has an advantage of simple operations without special knowledge, however the system is not able to direct how a trainee articulates the vocalization for the better vocalization during the training. By examining the problems of the conventional training systems, the authors are constructing an interactive training system, by which a patient engages in speech training in any occasion, at any place, without special knowledge.

(a) WH-9600 (Matsushita Electric Industrial Co., Ltd.) *(b) JX-1 (Bodysonic Co., Ltd.)*

Figure 1. *Examples of electronic speech training systems.*

The authors are developing a talking robot by reproducing a human vocal system mechanically based on the physical model of human vocal organs (Kitani et al, 2008). The robot consists of motor-controlled vocal organs such as vocal cords, a vocal tract and a nasal cavity to generate a natural voice imitating a human vocalization. For the autonomous acquisition of the robot's vocalization skills, an adaptive learning using an auditory feedback control is employed. In the previous study, the talking robot was applied to the training system of speech articulation for the hearing impaired children, since the robot is able to reproduce their vocalization and to teach them how it is improved to articulate the vocal organs for generating clear speech. The basic concept of the training system is shown in Figure 2.

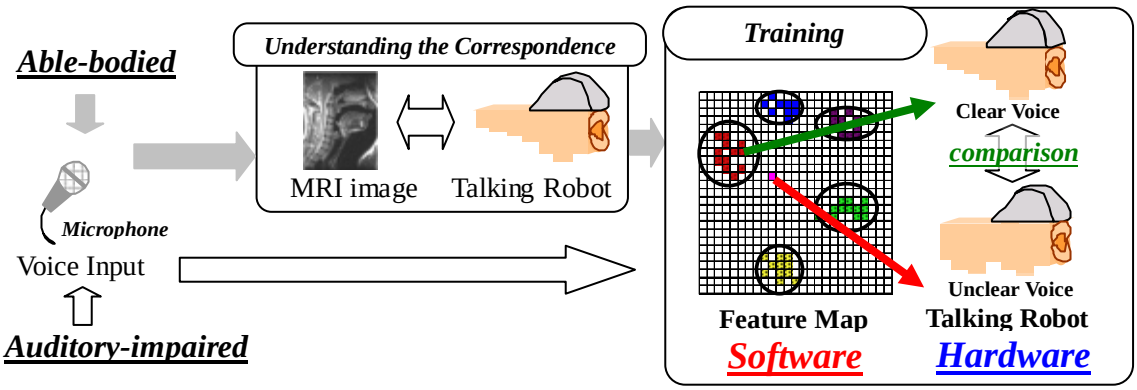


Figure 2. *Scheme of speech training system.*

The training is given by two approaches; one is to employ the talking robot for directing the shape and the motion of the vocal organs (hardware training), and the other is to use a topological map for presenting the difference of phonetic features of trainee's voices (software training). Prior to the experiments, the MRI images are presented to subjects to help understand the correspondence of human inner-mouth shapes with the robotic vocal tract shapes.

Firstly, an ideal vocal tract shape for a clear vocalization is presented to a trainee by the talking robot, and then the trainee tries to mimic the articulation of the vocalization by referring to the robot motion. Simultaneously, by listening to the trainee's voices, the robot reproduces the trainee's vocal tract shapes, and directs how the trainee's voice would be clarified by the change of articulatory motions, by intensively showing the different articulatory points. The trainee compares his own vocal tract shape and the ideal vocal

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

tract shape, both of which are shown by the articulatory motions of the robot, and tries to reduce the difference of the articulations. At the same time, the system also presents phonetic features using a phonetic topological map, in which the relations of the phonetic characteristics of trainee's voices and the target voices are displayed. By repeating the utterance and listening, the trainee would be able to recognize the similarity of the phonetic features presented as the topological distance between his voice and the target voice, and tries to reduce the distance. In the training, a trainee repeats these training processes for learning 5 vowels.

For assessing the effectiveness of constructed system, we conducted an experiment in the Kagawa prefectural school for the deaf, and significant results were obtained. The system used the 2D feature map for locating the phonetic characteristics, and we found it could not locate the phonetic characteristics properly. Additionally, the neural network which we used for associating phonetic characteristics with motor control commands required a lot of control parameters and reactive settings for the better learning. With these reasons, an algorithm which enables the phonetic characteristics to be located properly in the topological map, and associates the phonetic characteristics with motor controls by reduced control parameters is strongly required. In this study, a new algorithm using two SOMs, called a dual-SOM, is introduced for the autonomous learning. In the following chapters, the construction of the robotic training system and the training experiments are described, together with the performance of the dual-SOM learning for the robotic voice articulations.

3. CONSTRUCTION OF A TALKING ROBOT

The talking robot mainly consists of an air pump, artificial vocal cords, a resonance tube, a nasal cavity, and a microphone connected to a sound analyzer, which, respectively, correspond to a lung, vocal cords, a vocal tract, a nasal cavity, and a human audition, as shown in Figure 3. An air flow from the pump is led to the vocal cords via an airflow control valve, which works for the control of the voice volume. The resonance tube as a vocal tract is attached to the vocal cords for the manipulation of resonance characteristics. The nasal cavity is connected to the resonance tube with a rotary valve settled between them. The sound analyzer plays a role of the auditory system, and realizes the pitch extraction and the analysis of resonance characteristics of generated sounds in real time, which are necessary for the autonomous learning of vocalization skill. The system controller manages the whole system by listening to the vocalized sounds and calculating motor control commands, based on the auditory feedback control mechanism employing a neural network learning. The relation between the phoneme characteristics of generated voice and motor control parameters is stored in the system controller, which is referred to in the generation of speech performance.

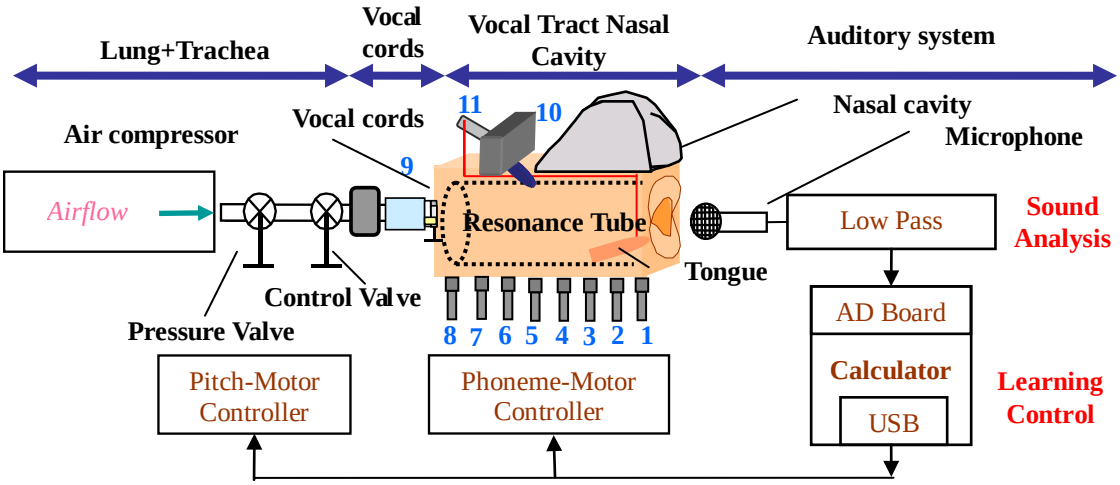


Figure 3. *Construction of a talking robot.*

The characteristics of a glottal wave which determines the pitch and the volume of human voice is governed by the complex behavior of the vocal cords. It is due to the oscillatory mechanism of human organs consisting of the mucous membrane and muscles excited by the airflow from the lung. Although several researches about the computer simulations of the movements are found, we are trying to generate the wave by a mechanical model. We employed an artificial vocal cord used by people who had to remove their vocal cords because of a glottal disease. The vibration of a rubber with the width of 5mm attached over a plastic body makes vocal sound source. The tension of the rubber can be manipulated by applying tensile force. We measured the relationship between the tensile force and the fundamental frequency of a vocal sound generated by the artificial vocal cord (Higashimoto & Sawada, 2003). The fundamental frequency varies

©2010 ICDVRAT; ISBN 978 07049 15022

from 110 Hz to 350 Hz by the manipulations of a force applying to the rubber. While, the relation between the produced frequency and the applied force is not stable but tends to change with the repetition of experiments due to the fluid dynamics. The artificial vocal cord is, however, considered to be suitable for our system not only because of its simple structure, but also its frequency characteristics to be easily controlled by the tension of the rubber and the amount of airflow. For the adjustments of fundamental frequency and volume, two motors are employed: one is to manipulate a screw of an airflow control valve, and the other is to apply a tensile force to the rubber of the vocal cord for the tension adjustment.

The human vocal tract is a non-uniform tube about 170 mm long in man. Its cross-sectional area varies from 0 to 20 cm^2 under the control for vocalization. A nasal tract with a total volume of 60 cm^3 is coupled to the vocal tract. Nasal sounds such as /*m*/ and /*n*/ are normally excited by the vocal cords and resonated in the nasal cavity. Nasal sounds are generated by closing the soft palate and lips, not to radiate air from the mouth, but to resonate the sound in the nasal cavity. The closed vocal tract works as a lateral branch resonator and also has effects of resonance characteristics to generate nasal sounds. Based on the difference of articulatory positions of tongue and mouth, the /*m*/ and /*n*/ sounds can be distinguished with each other.

In the mechanical system, a resonance tube as a vocal tract is attached at the sound outlet of the artificial vocal cords. It works as a resonator of a source sound generated by the vocal cords. It is made of a silicone rubber with the length of 180 mm and the diameter of 36 mm, which is equal to 10.2 cm^2 by the cross-sectional area. The silicone rubber is molded with the softness of human skin, which contributes to the quality of the resonance characteristics. In addition, a nasal cavity made of a plaster is attached to the resonance tube to vocalize nasal sounds like /*m*/ and /*n*/.

By actuating displacement forces with stainless bars from the outside, the cross-sectional area of the tube is manipulated so that the resonance characteristics are changed according to the transformations of the inner areas of the resonator. DC motors are placed at 8 positions x_j (j = 1-8) from the intake side of the tube to the outlet side, and the displacement forces P_j (x_j) are applied according to the control commands from the phoneme-motor controller. A nasal cavity is coupled with the resonance tube as a vocal tract to vocalize human-like nasal sounds by the control of mechanical parts. A rotational valve as a role of the soft palate is settled at the connection of the resonance tube and the nasal cavity for the selection of nasal and normal sounds. For the generation of nasal sounds /*n*/ and /*m*/, the rotational valve is open to lead the air into the nasal cavity. By closing the middle position of the vocal tract and then releasing the air to speak vowel sounds, /*n*/ consonant is generated. For the /*m*/ consonants, the outlet part is closed to stop the air first, and then is open to vocalize vowels. The difference in the /*n*/ and /m/ consonant generations is basically the narrowing positions of the vocal tract. In generating plosive sounds such as /*p*/, /*b*/ and /*t*/, the mechanical system closes the rotational valve not to release the air in the nasal cavity. By closing one point of the vocal tract, air provided from the lung is stopped and compressed in the tract. Then the released air generates plosive consonant sounds like /*p*/ and /*t*/. The robot also has a silicone-molded tongue, which is made by referring to the shape and size of a human. A string is attached to the tongue, and at the other end of the string, a servo motor is connected for the manipulation of the up-down motion, to articulate the vocalization of /*l*/ sounds.

4. METHOD OF AUTONOMOUS VOICE ACQUISITION

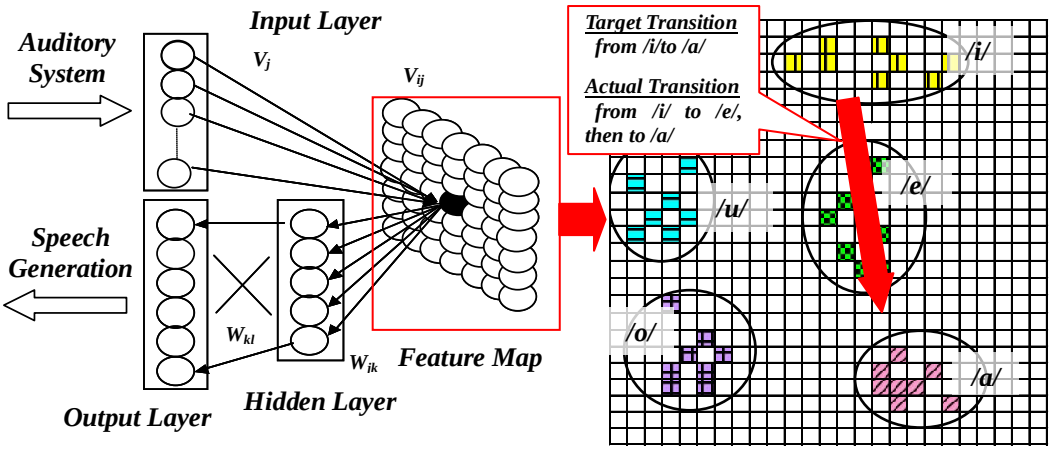
In the previous work, the Self-organizing Neural Network (SONN) was employed for associating phonetic characteristics with motor control commands (Sawada & Nakamura, 2004; Sawada, 2007). The SONN has a 2 dimensional feature map for locating phonetic characteristics as shown in Figure 4. In each cell on the feature map, the phonetic characteristics and motor control commands are buried by establishing topological relations, and with neighborhood learning of the SOM, similar phonetic characteristics are located close with each other.

As shown in a bold arrow in the figure 4 (b), when two cells are chosen from one cell to the other on the feature map (in this case, the voice from /*i*/ to /*a*/), the voice transition is obtained by selecting cells under the path connecting the two cells. However, if another vocal sound is situated on the path (voice area /*e*/ is situated in the map), the different voice is vocalized during the transition. This problem possibly occurs in the improper learning of the phonetic characteristics, and for solving this problem a new algorithm which enables the voice learning to locate all the voice features in proper locations on the map is required.

A 3D SOM which has 3 dimensional mapping space is introduce in this study for properly locating the phonetic characteristics. By applying 3 dimensional space, the characteristics are located 3 dimensionally, and the probability that the SOM generates improper locations would be decreased. Figure 5 shows a

©2010 ICDVRAT; ISBN 978 07049 15022

mapping result of the phonetic characteristics. The phonetic parameters are well mapped three dimensionally, and five vowels are categorized with one another by the learning of the SOM.



a) Structure of Self-organizing Neural Network *b) Feature Map*

Figure 4. *Previous learning method.*

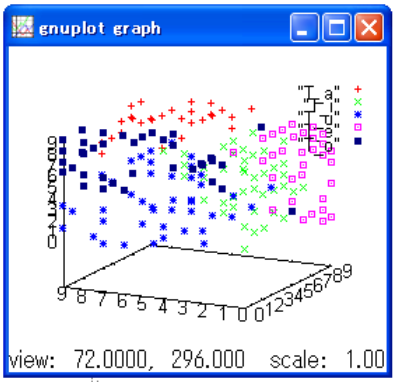


Figure 5. *Mapping result.*

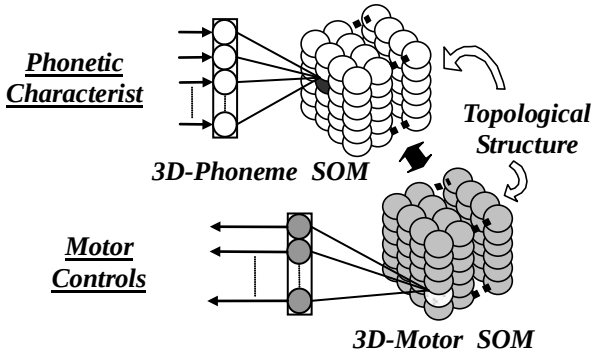


Figure 6. *Structure of dual-SOM.*

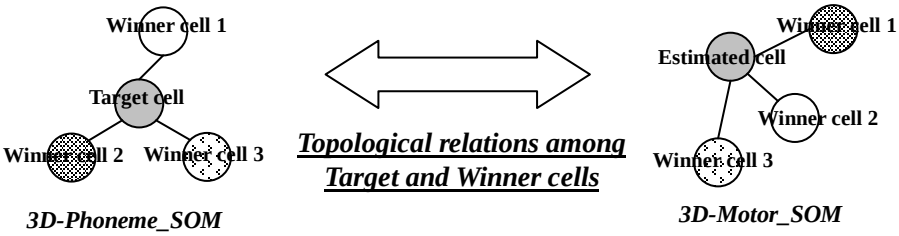


Figure 7. *Association of 3D-Phoneme_SOM with 3D-Motor_SOM.*

A dual-SOM is employed to associate the motor control commands of the robot with the phonetic characteristics of generated voices. The structure of the dual-SOM is shown in Figure 6, which consists of two self-organizing maps. One is a 3D-Motor_SOM, which describes the topological relations of various shapes of the vocal tracts, in which close shapes are arranged in close locations with each other, and the other is 3D-Phoneme_SOM, which learns the relations among phonetic features of generated voices. The talking robot generates various voices by changing its own vocal tract shapes. Generated voices and vocal tract shapes have the physical correspondence, since different voices are produced by the resonance phenomenon of the articulated vocal tract. This means that similar phonetic characteristics are generated by similar vocal tract shapes. By adaptively associating the 3D-Phoneme_SOM with the corresponding 3D-Motor_SOM, we could expect that the talking robot autonomously learns the vocalization by articulating its vocal tract.

In the learning phase, the motor control commands and the corresponding phonetic characteristics consisting of 9th order LPC cepstra are obtained by random articulations of the talking robot, and are

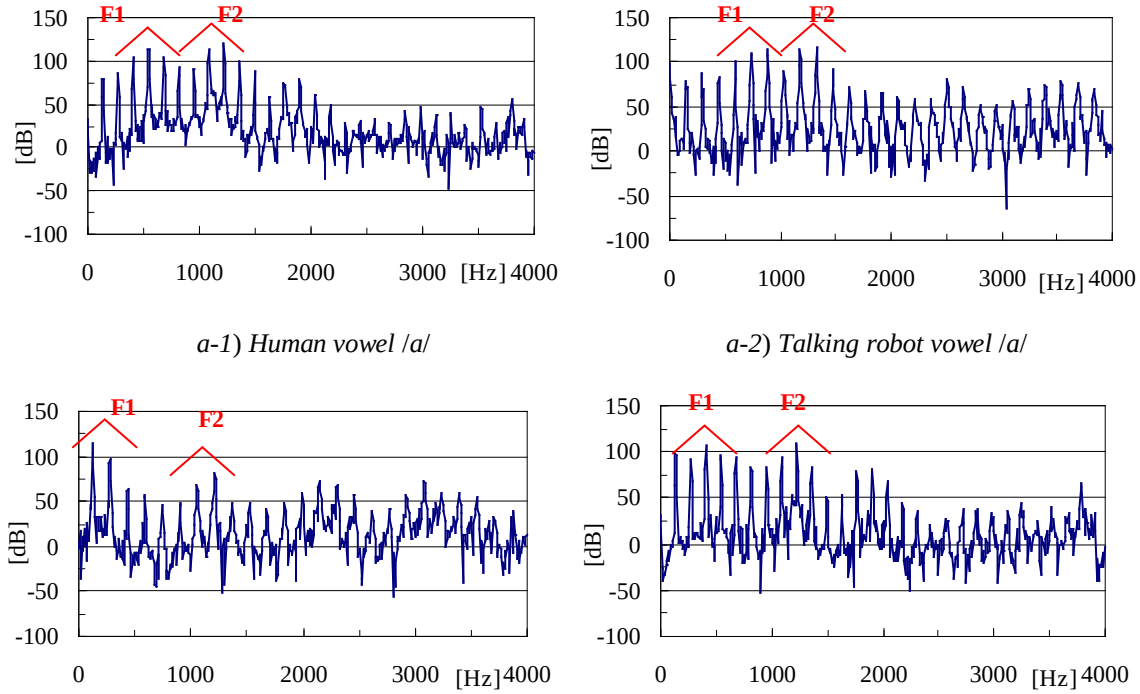
©2010 ICDVRAT; ISBN 978 07049 15022

inputted to the 3D-Motor_SOM and the 3D-Phoneme_SOM, respectively. The topological structures are autonomously established by the neighborhood learning on each SOM, so that similar patterns are located close with each other, and different patterns are located apart. The differences among patterns appear as the norm information in the three dimensional space in the SOM, so we tried to associate the two maps with each other by referring to the norms among a target cell and winner cells, which are shown in Figure 7. First, in the 3D-Phoneme_SOM, the distances from a target cell to the selected 3 winner cells are calculated, and the topological relations among 4 cells are also obtained. Then, by applying the topological relations to the 3D-Motor_SOM, the location of a cell from the corresponding 3 winner cells is estimated. The estimated location in the 3D-Motor_SOM would generate the corresponding vocal tract shape given by the phonetic features of the inputted sound.

5. LEARNING RESULT OF VOICE ARTICULATION

For the validation of the voice learning, we conducted an experiment of the robotic voice generation. Figure 8 shows the results of acquired spectra of /*a*/ and /*u*/ vowels, in comparison with actual human voices, and we found that the phonetic characteristics of Japanese vowels were well reproduced. Human vowel /*a*/ has the first formant in the frequency range from 500 to 900 Hz and the second formant from 900 to 1500 Hz, and the robotic voice also presents the two formants in the range. In the listening experiments, most of the subjects pointed out that the generated voices have similar phonetic characteristics to the human voices. These results show that the vocal tract made by silicone rubber has the tolerance of generating human-like vocalization, and application of the dual-SOM for the voice acquisition was well achieved.

Figure 9 shows the results of the transition of Japanese vowels from */u/* to */o/*. The figure *a*) shows the transition of phonetic characteristics buried in the 3D-Phoneme_SOM, and the figure *b*) shows the transition of motor control parameters obtained by the 3D-Motor_SOM. The abscissas show the time steps of the transition, and the ordinates show the phonetic characteristics and the motor control values, respectively. As the phonetic characteristics changed its values from */u/* to */o/*, the corresponding motor control values changed gradually as expected. The table *c*) shows the selected cells on the 3D-Phoneme_SOM and 3D-Motor_SOM through the transition from */u/* to */o/*. The left side column shows the time steps of the transition, and X Y Z shows the coordinates of the cells in two SOMs. Through the transition, selected cells were gradually changing its positions from */u/* to */o/*. This result confirms the cells on two SOMs were properly chosen. By the use of the three dimensional space for the mapping, the transitions were properly generated, and the results presented that the associations between two SOMs were well achieved.

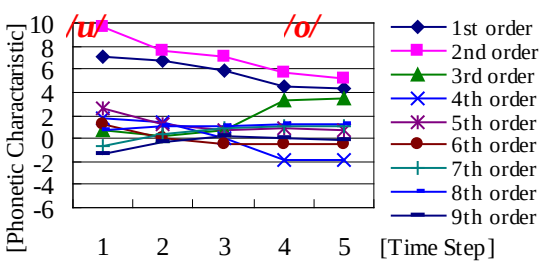


a-1) *Human vowel /a/* *a-2*) *Talking robot vowel /a/*

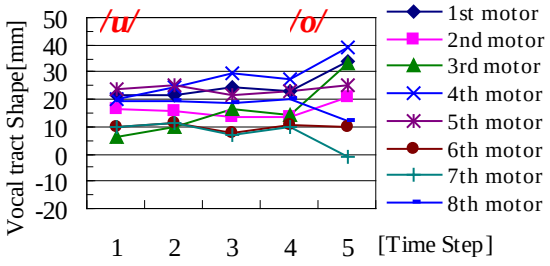
b-1) *Human vowel /u/* *b-2*) *Talking robot vowel /u/*

Figure 8. *Comparison of spectra.*

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022



a) 3D-Phoneme_SOM



b) 3D-Motor_SOM

	3D-Phoneme_SOM			3D-Motor_SOM		
	X	Y	Z	X	Y	Z
1	2	7	9	4	4	4
2	2	6	8	3	4	2
3	2	5	7	5	5	3
4	2	4	6	4	4	3
5	2	3	5	4	6	5

c) Selected cells on two SOMs

Figure 9. *Transition from /u/ to /o/ voices.*

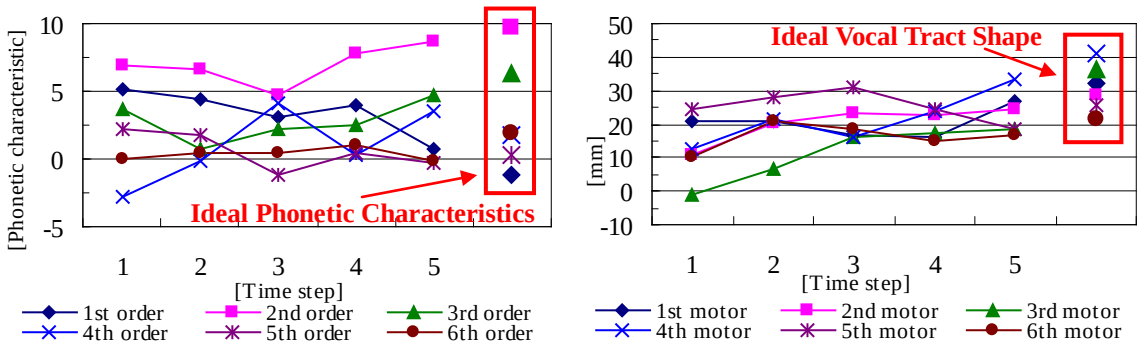
6. VOCALIZATION TRAINING BY APPLYING Dual-SOM

A training experiment was conducted in Kagawa Prefectural School for the Deaf. The training consists of two parts, one is to employ the robot for directing the articulatory motion of the vocal organs for a vocalization (hardware training), and the other is to present a 3D feature map on a computer display for presenting the difference of phonetic features of trainee's voices (software training). The trainee compares his own vocal tract shape with the ideal vocal tract shapes, both of which are shown by the articulatory motions of the robot, and tries to reduce the difference of the articulations. The system also presents phonetic features using the 3D topological map, in which the trainee's voice and the target voices are visually referred to by the topological relations. During the repetition of uttering and listening, the trainee recognizes the topological distance between his voice and the target voice, and tries to reduce the distance. In the training, a trainee repeats these training processes for learning 5 vowels. Six high school students and four junior-high school students (10 students in total) were engaged in the experiment.

Figure 10 shows the results of training /i/ and /o/ vowels for subject 1. In the figures of *a*) and *b*), the abscissas show the time steps of the training, and the ordinates show the phonetic characteristics and the vocal tract shapes reproduced by the talking robot, respectively. As the training proceeds, the phonetic characteristics and the corresponding vocal tract shapes of the vowels were getting close to the ideal ones given by able-bodied speech. These results confirmed that the subject 1 learned the vocalization properly. The figure *c*) shows the training results of the 5 vowels. In the 3D Feature Map shown in figure *c*), each marker presents the locations of 5 vowels, where same colors show the same vowels. The greater markers present the averaged locations of 5 vowels given by able-bodied speech, and small markers present the vocalization of subject 1. Table *d*) shows the selected cells in the 3D feature map, in which the left side column shows the 5 vowels, and X Y Z shows the coordinates of the cells in the map. Before the training, the locations of the selected cells were far from the able-bodies speech, however after the training, selected cells were located closer to the coordinates of the ideal ones. The results verified that the subject 1 successfully acquired the proper vocalizations by the interactive training.

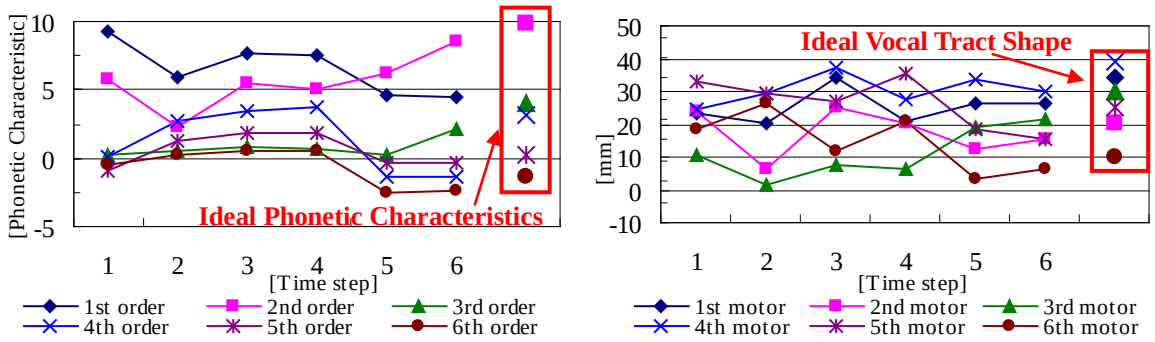
Figure 11 shows the result of the training of /u/ vowel of subject 2. The abscissas and the ordinates in the figures *a*) show the same parameters as presented in the figure 10. Both phonetic features and reproduced vocal tract shapes given by the subject 2 voices were far different from the ideal values, and selected cells on the 3D feature map were located far from the vowel /u/ ideal location. The subject claimed the difficulty of understanding the relations of phonetic features presented three dimensionally, and he pointed out the necessity of much intuitive understanding of articulations in the mouth.

©2010 ICDVRAT; ISBN 978 07049 15022



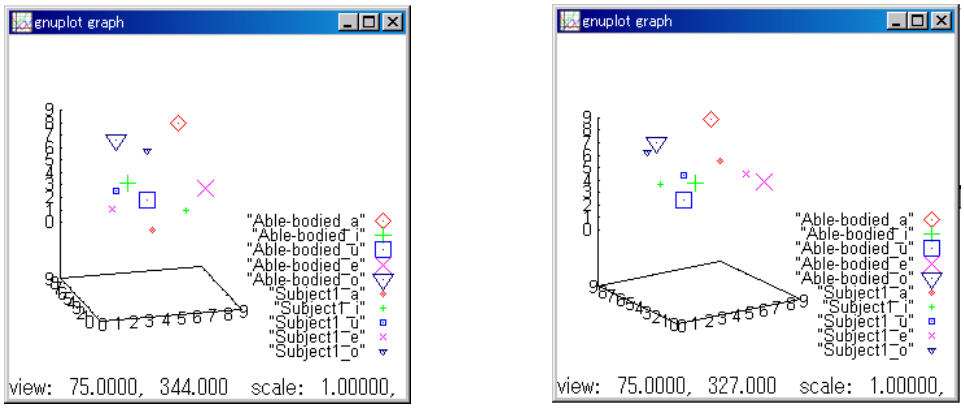
a-1) Phonetic characteristics *a-2) Vocal tract shapes*

a) Characteristics of training /i/ on 3D feature map



b-1) Phonetic characteristics *b-2) Vocal tract shape*

b) Characteristics of training of /o/ on 3D feature map



c-1) Before Training *c-2) After Training*

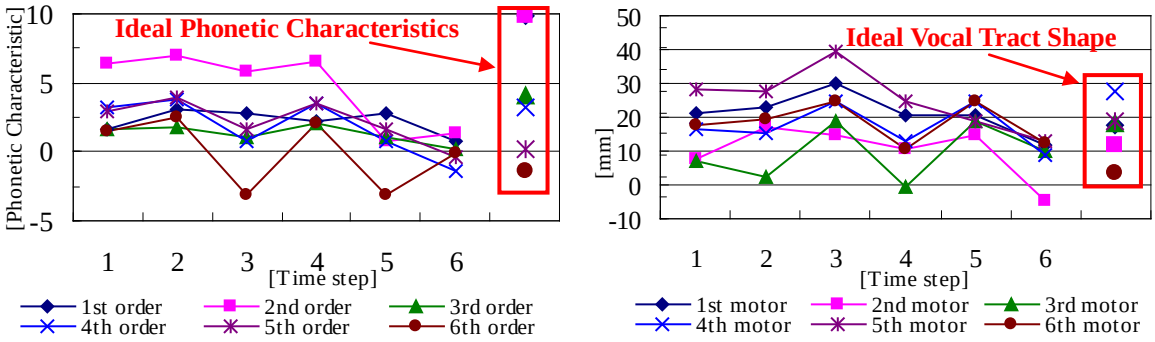
c) 3D feature map of Subject 1

Vowels	Before Training			After Training			Able-bodied Vocalization		
	X	Y	Z	X	Y	Z	X	Y	Z
/a/	5	6	0	7	6	5	7	7	8
/i/	6	2	3	0	2	6	2	1	6
/u/	3	7	3	5	7	4	5	7	2
/e/	1	1	4	7	3	5	7	1	5
/o/	5	7	6	3	8	6	3	7	7

d) Selected cells on 3D Feature Map

Figure 10. *Training Result of Subject 1.*

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022



a-1) Phonetic characteristics *a-2) Vocal tract shape*

a) Characteristics of training of /u/ on 3D feature map

Vowels	Before Training			After Training			Able-bodied Vocalization		
	X	Y	Z	X	Y	Z	X	Y	Z
/a/	1	9	1	7	6	8	7	7	8
/i/	2	4	9	2	2	5	2	1	6
/u/	5	8	8	7	9	8	5	7	2
/e/	4	0	0	2	2	4	7	1	5
/o/	0	9	0	4	4	8	3	7	7

b) Selected cells on 3D Feature Map

Figure 11. *Training Result of Subject 2*

By the robotic speech training, 7 students out of 10 could successfully improve their vocalization, and the left 3 students partly learned the articulations for the better vocalization. These results verified that the speech training employing the robot and the intuitive directions helped the trainees understand how to articulate the speech for the clear vocalization. In the questionnaire after the training, most subjects answered that the training with the robot was fun, and all of them gave the positive participation to the training.

7. CONCLUSION

In the paper a new learning method of the autonomous vocalization for a talking robot employing a dual-SOM was introduced, and the robot was applied to the interactive training for the auditory-impaired people. By analyzing the problem of previously-introduced algorithm using a SONN, we constructed a new algorithm using two SOMs to establish topological relations of the phonetic characteristics with motor-control parameters in a three dimensional space. By utilizing the autonomous learning of phonetic features of vocal sounds, the robot was employed in the speech training for auditory-impaired students. The experimental results verified the effectiveness of the interactive training using a robot and the intuitive directions of vocal characteristics. We are now working to construct the better training system which could estimate and show the detailed phonetic characteristics of the trainee.

Acknowledgements: This work was partly supported by the Grants-in-Aid for Scientific Research, the Japan Society for the Promotion of Science (No. 21500517). The authors would like to thank Dr. Yoichi Nakatsuka, the director of the Kagawa Prefectural Rehabilitation center for the Physically Handicapped, Mr. Tomoyoshi Noda, the speech therapist and teacher of Kagawa Prefectural School for the Deaf, and the students of the school for their helpful supports for the experiment and the useful advice.

8. REFERENCES

A. Boothroyd: “Hearing Impairments in Young Children”, A. G. Bell Association for the Deaf, 1988.

A. Boothroyd: “Some experiments on the control of voice in the profoundly deaf using a pitch extractor and storage oscilloscope display”, IEEE Transactions on Audio and Electroacoustics, Vol.21, No.3, pp. 274-278, 1973.

N. P. Erber and C. L. de Filippo: “Voice/mouth synthesis and tactual/visual perception of /pa, ba, ma/”, Journal of the Acoustical Society of America, Vol.64, No.4, pp.1015-1019, 1978.

M. H. Goldstein and R. E. Stark: “Modification of vocalizations of preschool deaf children by vibrotactile and visual displays”, Journal of the Acoustical Society of America, Vol.59, No.6, pp.1477-81, 1976.

M. Kitani, Y. Hayashi and H. Sawada: “Interactive training of speech articulation for hearing impaired using a talking robot”, International Conference on Disability, Virtual Reality and Associated Technologies, pp.293-301, 2008.

T. Higashimoto and H. Sawada: “A Mechanical Voice System: Construction of Vocal Cords and its Pitch Control”, International Conference on Intelligent Technologies, pp. 762-768, 2003.

H. Sawada and M. Nakamura: “Mechanical Voice System and its Singing Performance”, IEEE/RSJ International Conference on Intelligent Robots and Systems, pp. 1920-1925, 2004.

H. Sawada: “Talking Robot and the Autonomous Acquisition of Vocalization and Singing Skill”, Chapter 22 in Robust Speech Recognition and Understanding, Edited by Grimm and Kroschel, pp.385-404, June 2007.

©2010 ICDVRAT; ISBN 978 07049 15022

Automatic speech recognition for assistive technology devices

A P Harvey[1], R J McCrindle[2], K. Lundqvist[3] and P Parslow[4]

[1,2,3,4]School of Systems Engineering, University of Reading,
Whiteknights, Reading, Berkshire, UK

[1]*a.p.harvey@rdg.ac.uk,* [2]*r.j.mccrindle@rdg.ac.uk;* [3]*k.o.lundqvist@rdg.ac.uk;* [4]*p.parslow@rdg.ac.uk*

[1,2,3,4]*www.reading.ac.uk/sse*

ABSTRACT

Speech offers great potential as a mode of interaction with devices to control our environment, support our work or assist us with tasks of daily living, however, to date the level to which this has been universally achieved and exploited has not matched its potential. Automatic Speech Recognition (ASR) is the process of interpretation of human speech by a machine. This may take two forms; continuous speech, as with human to human interaction or dictation, and discrete speech, such as commands issued to a device. ASR in the 'ENABLE' project uses discrete utterances to allow navigation of the user interface on a wrist worn device, control of the associated ECS (Environmental Control System) components as well as the ability to provide feedback for long term conditions using speech alone; features widely requested by users with a range of disabilities as well as by others for general ease of use. The aim of this paper is to explain the rationale and process behind the development of the ASR for the ENABLE device.

1. INTRODUCTION

Automatic Speech Recognition (ASR) is the process of interpretation of human speech by a machine. This may take two forms; continuous speech, as with human to human interaction or dictation, and discrete speech, such as commands issued to a device. Speech offers great potential as a mode of interaction with devices to control our environment, support our work or assist us with tasks of daily living. Recognition of continuous speech is primarily used to compose a document with dictated speech replacing the need to use a mouse and keyboard, whilst discrete speech recognition is most commonly used for command based activities such as those associated with automated call centres and non safety critical military applications. However, despite these examples, integration of ASR into systems that could benefit from its application has not been universally achieved and its exploitation despite having considerable potential and to date has fallen far short of expectations.

ENABLE is an EU project aimed at developing a wearable device that can be used both within and outside of the home to support older people in their daily lives and which can monitor their health status, detect potential problems, provide activity reminders and offer communication and alarm services. The system is built round a dual platform of mobile phone and wrist unit, to which are added modular capabilities for (1) alarm functions, (2) control of appliances/other devices around the home, (3) identification of the user's location, and (4) health monitoring. The project also addresses mobile phone accessibility by providing an accessible user interface extension, using the wrist unit and speech guidance.

ASR in the ENABLE project uses discrete utterances to allow navigation of the user interface on a wrist worn device, control of the associated ECS (Environmental Control System) components as well as the ability to provide feedback for long term conditions monitoring using speech alone; features widely requested by users with a range of disabilities as well as by others for general ease of use. In total 132 commands have to be recognised in order to fully operate the wrist unit (WU) including commands such as 'back', 'select, 'up', 'down', 'light-on', 'blinds up', 'play', 'rewind', etc. A full list of the commands is given in Figure 1 at the end of the paper. The aim of this paper is to explain the rationale and process behind the development of an ASR system for the ENABLE device and to discuss the key challenges associated with implementing ASR on a wearable assistive technology device.

©2010 ICDVRAT; ISBN 978 07049 15022

2. EXISTING ASR SYSTEMS

2.1 Speech Recognition Engines

Many speech recognition engines/systems are available on commercial and open-source licences such as Google Voice Search [Google, 2010], Nuance (Philips) [Nuance, 2010], LumenVox [Lumenvox, 2010], Loquendo [Loquendo, 2010], Cambridge HTK [HTK, 2010], simon [Speechtotext, 2010] and CMU Sphinx [CMU, 2010] each having different strengths, weaknesses and capabilities that make them appropriate for different tasks. A number of speech research groups across Europe including the ESAT Speech Group, K.U.Leuven, Belgium [ESAT, 2010], the Wire Communications Laboratory, University of Patras, Greece [Patras, 2010], and the Speech Processing Group, Brno University of Technology, Czech Republic [Brno, 2010] are also developing new ASR engines for specific localisations and improvement of existing engines for particular languages.

2.2 Projects Incorporating ASR

A range of projects incorporating ASR have been/are being undertaken all of which whilst interesting, have a different application area/focus, or which only partially address the combination of aspects of ASR that are required by the ENABLE system. These projects include: Luna [Luna, 2009], PAST (exPeriencing Archaeology across Space and Time) [MJC2, 2007], EASAIER (Enabling Access to Sound Archives through Integration, Enrichment and Retrieval) [Reiss, 2008], MAESTRO [Rivlin et al, 2000], Companions [Cavazza, 2010)], SynFace [SynFace, 2004], DICTATE [Nuance, 2010], Stardust [Hawley, 2003], Inspire [Inspire, 2004], Speecon [Speecon, 2000], IDAS [Patras, 2010], Amigo [Philips, 2007], Agent-DYSL [Agent-Dysl, 2009], Vital Mind [Cognifit, 2005] and HERMES [Jiang et al, 2009],

3. CHALLENGES ASSOCIATED WITH ASR

The numerous complexities associated with developing ASR systems have meant that traditional ASR systems have frequently not been fully appreciated by the end-user; have not been adapted to meet user requirements; must be specifically trained to an individuals' voice; or simply have not been able to recognise words with enough accuracy. For example:

- Differences in voice characteristics exist between users, compounded by different accents/dialects and sometimes entirely different pronunciations.
- Similarity of certain words and confusion of sounds such as 'n' and 'm'.
- Short words are more difficult to recognise as there is much less data to process and context within which to place it, e.g. "up", "down" and other monosyllabic words.

This situation is further compounded if all or some users of the system are elderly people or they have some degree of impaired speech, e.g.:

- There may be less consistency in the voice of an elderly person due to tiredness.
- Medical conditions such as stroke, dysarthria, or breathlessness may affect speech.

There may be high levels of background noise e.g. due to the television or other people talking

4. ENABLE APPROACH TO DEVELOPMENT

4.1 Overall Approach to the ASR Development Process

Effective development is frequently a mix of integration and implementation – and this is the approach we have adopted in ENABLE. Indeed this approach is commonly adopted across many integrated research and development projects that involve ASR, the key decision being which engine to use (e.g. the proprietary systems of Loquendo, Nuance or Philips vs. open source systems such as Sphinx or simon). This decision to utilise a speech engine rather than develop our own as part of the ENABLE project was made for a number of reasons:

1. Many person-years of effort have been input into the development of the Sphinx (or similar) engine and to replicate this would not have added value to the project but would have consumed additional resources.

©2010 ICDVRAT; ISBN 978 07049 15022

2. In light of the project requirements it was far more important to develop the ASR models, grammars, functions and extensions required for the ASR to interface to and be integrated with the ENABLE system than to create an untested engine.
3. It makes sense to make use of the features such as the noise cancelling facility and automatic level control of the Sphinx engine and the audio chip embedded in the wrist unit.
4. It was possible to take advantage of the robustness of an engine that has been maturing over a number of years.

Following a period of initial investigation and prototyping, PocketSphinx, a state of the art open source speech recognition engine was selected as the foundation for the ENABLE ASR development, due to the reliability of its engine and its inclusion of various algorithms to compensate for noise and other external factors affecting the reliability of the recognition. However, 'out-of-the-box', PocketSphinx provides only a recognition engine and an audio model for North American English (and Mandarin in the latest version). A model in this sense comprises only phonemes and a statistical representation of each; it does not contain a corpus, dictionary or grammar all of which had to be created. A new model for each required language also had to be developed (including U.K. English).

Creating a new model for PocketSphinx to allow it to recognise words in other languages involved mapping phonemes and gathering audio data for each necessary language. Phonemes are specific to each language, even between dialects. For instance, U.K. English has 5 more phonemes than U.S. English. Once the audio data for each language was gathered, each recording was separated into its constituent phonemes for the purposes of training. Once this had been achieved, the recordings were processed to form a Hidden Markov Model (HMM). Further phonemic analysis of the command corpora was then performed to enhance the recognition rate for different English dialects and accents. From the work undertaken during this period of investigation, additional alternative pronunciations were added to enhance the models' performance characteristics. Vowels (and vowel sounds) were taken into particular account, alongside consonants with similar sounds, such as 'n' and 'm', etc.

Additionally, PocketSphinx provided only a simplistic API (Application Programming Interface) to interface with. A wrapper around this had to be developed for the ENABLE ASR system, to allow the Wrist Unit (WU) to start and stop the service to conserve battery life, pass memory locations to recordings of speech in order to return recognised utterances and provide a mechanism to 'jump' between branches in the finite state grammar tree (Figure 1). Essentially, the grammar is broken down into finite states where each non-terminal command 'leads' to a further set of commands. This means that each command can only be uttered in its intended position in the sequence of commands. Each position in the menu allows only a certain number of commands to be uttered, meaning that the potential for misrecognition is reduced to a proportion of the number of linked commands (see Figure 1 at the end of the paper). *This is context-sensitive ASR.*

4.2 Stages in the ASR Development Process

In order to implement the above approach a number of stages of development were undertaken. These are described below and summarised in Figure 2.

4.2.1 Stage 1 – Rapid Application Development. Initial work on the ASR system produced a speech recognition prototype based on Sphinx 4, an open source speech recognition engine

4.2.2 Stage 2 – Selection of Approach. The decision to use an available engine was made because of the reliability of current engines. Various techniques in speech recognition have been adopted as the standard, and attempting to improve on these in a relatively short period of time would likely prove unfruitful. However, as detailed above, using an engine does not mean that the difficulties are all overcome. Models, grammars, corpora, etc. must be produced for the engine, which is where the state-of-the-art developments for the ENABLE Wrist Unit have focussed.

4.2.3 Stage 3 – Selection of Final Platform. The decision to switch development to 'PocketSphinx' was made after assessing the 'Sphinx' engine. It was found to be robust, but far too heavyweight to run on an embedded device. A number of speech recognition engines were evaluated, considering their expected performance on low-power hardware, the nature of their associated licences, cost and system requirements. PocketSphinx was chosen based on its performance, appropriate system requirements, its similarity to the already developed Sphinx prototype and the permissive nature of its licence.

©2010 ICDVRAT; ISBN 978 07049 15022

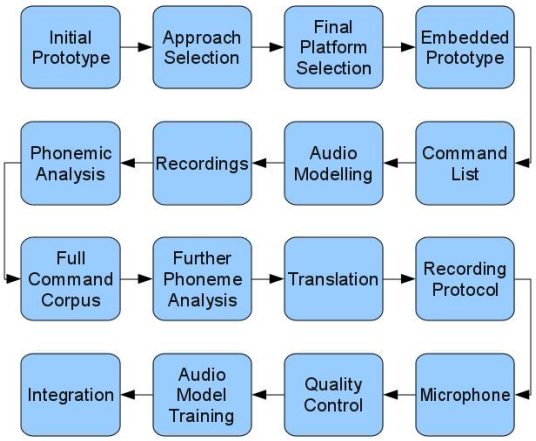


Figure 1. *Development Stages for the ENABLE ASR System.*

4.2.4 Stage 4 – Prototype Development. A preliminary software prototype was produced to develop, test, analyse and modify underlying audio and language models using PocketSphinx. A new language (audio) model based on a Finite State Grammar has been developed and integrated into the PocketSphinx based toolset. This Finite state grammar forms the basis of the menu structure within the ASR system; it can be (and has been) expanded to cover a wider range of commands or modified to produce a new structure based on the requirements of the user and the menu in the user interface of the ENABLE device.

4.2.5 Stage 5 – Command List. A corpus of possible commands was produced for the PocketSphinx prototype. This corpus was based on the available commands/functions used in previous demonstrations of the ENABLE prototype. Each command was taken from the UI (User Interface) menu structure and added to the corpus, and its place within the structure recorded in the finite state grammar. Each word was then broken down into its constituent phonemes to form a command list that PocketSphinx is able to use to identify words. This corpus was subsequently translated into Czech, Dutch, German and Greek, and initial phonemic analysis of the commands was executed to comprise command lists similar to the format used for the English list, appropriate for the PocketSphinx engine.

4.2.6 Stage 6 – Modelling. This preliminary model was used to test audio modelling using existing corpora to identify problems between different words. A basic grammar was used, expecting only a single word at each utterance. This allowed words from the initial set of demonstrated commands to be verified against each other, and words which may be easily misrecognised as other words to be easily identified. Where such confusion was likely, alternative words were identified, and then analysed for the likelihood of the words existing at the same point in the grammar (i.e. could these words be options as part of the same sub-menu).

4.2.7 Stage 7 – Recordings. A series of audio recordings were taken for the initial command set in English. This included people of varying backgrounds, accents, ages and genders. These recordings have been used in a number of ways; to test the performance and reliability of the system, to further enhance the audio models used by the system to enhance its reliability and form a basis for an audio recording protocol to capture further audio samples in all partner languages. Further recordings of this command set were made at the pilot sites in Czech, Danish, Dutch, German and Greek. Similarly, these recordings were used to produce a basic model for each language, utilising the initial command corpus.

4.2.8 Stage 8 – Improvements. Further phonemic analysis of the command corpora was performed to enhance the recognition rate for different English dialects and accents. From the work undertaken during this period of investigation, additional alternative pronunciations were added to enhance the models' performance characteristics. Vowels (and vowel sounds) were taken into particular account, alongside consonants with similar sounds, such as 'N' and 'M', etc. Adjustments were made to the models for the other languages based on the results of the tests performed using the obtained audio samples. These improvements were tested with these recordings to gauge the level of improvement, or readjust where necessary.

4.2.9 Stage 9 – Full Corpus. After testing of the prototype, and confirmation of various techniques for the modelling of languages other than English, the full command corpus for the ENABLE device was defined. This command list was formed from input from various partners, including an assessment of all of the underlying functions of the device. The fundamental objective for development of the corpora was to ensure that the ENABLE device ASR function could deliver all command features in the voice control module.

©2010 ICDVRAT; ISBN 978 07049 15022

Other words, such as locations, were added to the device as potential shortcuts, allowing various menu items to be accessed from other areas in the menu structure.

4.2.10 Stage 10 – Detailed Phoneme Analysis. A detailed analysis of the English command list was performed to identify the phonemes comprising each word. This determined which phonemes were appropriate for the commands specified, and analysed the words to incorporate different sounds and different interpretations of the audio recordings, depending on the quality (background noise, etc.) to ensure the best possible matches for each. The analysis also included an investigation of the positions of the vowels in the words, and the addition of similar sounding vowel phonemes as duplicate definitions of those words to allow for different accents, dialects and any degradation of voice.

4.2.11 Stage 11 – Translations. Translations into Czech, Dutch, French, German and Greek were completed and a programme of work to analyse the full command list was undertaken and the resulting constituent phonemes were correlated with the English equivalent. The lists of phonemes produced, similar to those used in the prototype, were used alongside the current audio models and tested.

4.2.12 Stage 12 – Recording Protocol. A new audio recording protocol, specific to the ENABLE project, was defined, specifying the process to be followed when taking audio samples. It specifies that participants select (although the rest of the process is applicable to any voice recording for any participants), how the words in a command list should be recorded together/individually, including special instructions for alternative pronunciations and synonyms, the naming conventions to be used for files and potential methods of delivery of the files. This protocol was followed locally at Reading to test it, and to obtain recordings in English before passing it to other Partners.

4.2.13 Stage 13 – Microphone. All recordings taken were using the same model of microphone included in the ENABLE device, albeit attached to a PC or other recording device. This is important, as different microphones have different dynamic ranges, and thus produce different sounds to other similar microphones. Due to the nature of these and other characteristics of potential microphones, it is essential for a functioning ASR system to utilise a suitable microphone and thus obtain a consistent signal. The microphone chosen is a highly directional model, meaning that most of the recorded sound should be from the direction of the participant. This also contributes to the success of the ASR system by not recording a substantial proportion of the background noise in general operation.

4.2.14 Stage 14 – Quality Control. Returned recordings were examined for quality, ensuring that there were no interruptions from loud noises in the background, labels were correct and audio levels were sufficient. Where possible, these were corrected with software so as not to distort the recording, and/or re-recorded. Using the lists of phonemes produced for each language, each recording was transcribed into its constituent phonemes. Large periods of silence were removed, along with coughs, sneezes, etc. With the recordings, adjustments were made to the list of phonemes where appropriate, to ensure the best fit for training the models.

4.2.15 Stage 15 – Training the Models. Each recording and accompanying transcription was used to train a language dependent model. A tool for this is provided with Sphinx. The trained models were then tested, and further phonemic analysis was performed against the recordings in all languages. Scripts were defined for testing against the existing models to semi-automate the process. Adjustments were made to the audio models and phoneme compositions as and where necessary. Adaptation and tweaking of the audio models was performed as necessary after testing.

4.2.16 Stage 16 – Integration. In preparation for integration with the other features designed and developed for the wrist device, cross-compilation of modules and libraries for use on embedded hardware was completed for all components necessary for ASR. After further checks and verification of the compilation process for non-x86-based hardware, the process of integrating the ASR system into the build-tree began during an 'Integration Week'.

Consultation with the relevant technical partners regarding the basis for the integration of PocketSphinx was established and commenced with writing a 'Make' file to extract and build the libraries, before inserting them into the correct locations within the build-tree. This file was linked back into the main build-tree so that the process of compiling the entire tree would include the ASR libraries.

A plug-in for the existing user interface was created, which loads the ASR system, passes it details about the language and grammar to use for the session, passes the audio recordings for recognition and manages the returned strings to the user interface. This plug-in is the core of the integration work for ASR and manages all

©2010 ICDVRAT; ISBN 978 07049 15022

aspects of the ASR subsystem. Initial work on the ASR system produced a speech recognition prototype based on Sphinx 4, an open source speech recognition engine

The ASR requires a different integration strategy than the other ENABLE services such as the falls detection and environmental control system (ECS) which can be effectively implemented as stand-alone plug-ins. As each ASR commend has to evoke a different response in the system each command has to be associated with an action both in the main navigation part of the code and for each action within each of the sub-sections; thus making integration a more complex issue.

5. RESULTING ASR FEATURES IN THE ENABLE SYSTEM

The following key state-of-the-art features have been developed as part of the ENABLE ASR system:

- Development of a new language (audio) model based on a Finite State Grammar which forms the basis of the menu structure (130 words in total) within the ASR system and which is extensible to meet the requirements of the user, or for inclusion of future wrist unit functionalities. The ENABLE ASR system utilises PocketSphinx, a state of the art open source speech recognition engine. On top of this engine, the speech models, in Hidden Markov Model (HMM) form, are passed to the engine for processing. This provides a basis for the individual phonemes to be recognised on a probability basis to form words. These words are included in the corpus for each language, as described above. The words are recognised by forming Markov Chains in the model; these are the most likely 'paths' through the model that the spoken word may take.
- Creation of a multi-lingual command corpus (English, Czech, Dutch, German and Greek). A series of language and speech models have been produced for the each of the languages involved in the WP11 pilot trials. These are 'compiled' versions of speech recordings from EPs for a particular language, forming a HMM for each. A corpus of all possible words which may be spoken to the device has been defined for each language. These provide a definition of each of the phonemes (or potential phonemes where more than one is possible in different dialects) which form each word.
- Development of a context-sensitive mechanism to lessen the likelihood of misrecognition of words (through structured grammar). Each wrist device can be configured with a menu structure specific to the ECS configuration related to the user. The specific menu structure will generate an ASR grammar specific to that configuration. The grammar is broken down into finite states where each non-terminal command 'leads' to a further set of commands. This means that each command can only be uttered in its intended position in the sequence of commands. Each position in the menu allows only a certain number of commands to be uttered; meaning that the potential for misrecognition is reduced to a proportion of the number of linked commands.
- Minimisation of ambient noise by including with each language's audio model recordings of various imperfections in speech input, such as pops, hisses and crackles and other background noises so that the speech recognition engine can detect such noise and ignore it. Included with each language's audio model are recordings of various imperfections in speech input, such as pops, hisses and crackles and other background noise. This is designed to enable the speech recognition engine to detect such noise and ignore it. Combined with a specifically chosen directional microphone, and a software gate and compressor system to normalise the speech input (providing a threshold), the ASR system takes input from a robust speech input device.
- Development of an ASR system capable of running on embedded hardware (without the need for an external server to handle the model processing). A major constraint relating to the design of the architecture was the necessity to integrate the ASR into an existing system. This is coupled with the embedded nature of the device (slower, non-x86-based hardware) and the modular nature of the ECS system; all features of ECS have the ability to be controlled by the ASR, which uses a fixed grammar rather than the ever changing structure of the ECS menu, which depends on a number of factors, including location
- Creation of an ASR system that will work in all partner languages (English, Czech, Dutch, German and Greek) and which can be extended to include all languages/dialects.
- Speaker independence for majority of older people removing the need for voice training. As the models are created from a large set of transcribed audio, the ASR system is speaker-independent for the majority of elderly users. This means that the EP will not have to train the ASR system to their

©2010 ICDVRAT; ISBN 978 07049 15022

own voices, which has been identified as a source of dissatisfaction and problems with other speech recognition systems

- Ability to develop speaker dependent language models based on an elderly person's long term condition (e.g. stroke). A new language model based on an individual's speech patterns could be developed in a similar manner to developing a new model for an additional language/dialect.
- Working ASR system on the wrist unit within a 2 second processing limit

Whilst each of the above features in itself is not totally unique, as other ASR systems can demonstrate one or more of the above features, the key innovation in ENABLE comes from having implemented ALL of the above features in a single device and on non-proprietary software such that "the whole is greater than the sum of its parts."

In contrast, many speech recognition systems are specific to a small set of languages, *are* limited to equipment with large amounts of processing power (and thus not portable), use natural language processing to attempt to recognise entire sentences or dictated/continuous speech or use the power of a server/multiple servers to process the speech remotely from the mobile device. This incurs high communication costs and increases the time taken to process each word (due to communication delays, server availability, load, etc.) and limits the device to areas within communication range.

Additionally, although some ASR based devices do work very effectively, many other current mobile speech recognition devices are considered to be inadequate; this has been highlighted in general public and internet opinion and in a number of conferences. Training is required for general speech recognition software on mobile devices*;* a significant challenge for the ENABLE ASR system was to produce a speaker independent speech recognition system, capable of recognition on a mobile device (wrist unit) with a suitable period of time. Most current state of the art speech recognition systems require training, powerful (fast) hardware and even then do not produce impressive results.

After all '*if ASR was easy to do it would be everywhere*'.

6. TESTING AND RESULTS

By adopting the context sensitive approach to ASR it reduces the number of words that need to be recognised at any one time and hence recognition rate should be improved. For example: Total states for each command in the ENABLE system without context sensitive ASR is 130. With Context sensitive ASR the number of states from which to select the correct word are considerably reduced (see Figure 1 and Table 1).

Table 1. *Examples of Context Sensitive ASR*

Case 1: Menu -> Remote Control -> Living Room -> Television -> Volume Up	**Case 2: Menu -> Remote Control -> Bedroom -> Lights Brighter**
Possible potential states: Menu: 9 Remote Control: 5 Living Room: 7 Television: 6 Volume up: 8	Possible potential states: Menu: 9 Remote Control:5 Bedroom: 7 Lights Brighter: 8

Word Recognition Rates (WRR) through this approach for each language model when tested under laboratory conditions are:

Table 2. *WRR for different language models in the ENABLE system.*

English 92.4%
German 88.6%
Dutch 75.8%
Greek 72.7%
Czech 69.7%

©2010 ICDVRAT; ISBN 978 07049 15022

The project is currently exploring several potential explanations for why words in some languages are recognised more easily than others, for example:

- The recordings taken could be better for some languages than others
- The nature of the language in question has different characteristics, so German, for instance, has some quite hard sounding consonants that are easy for Sphinx to identify, whereas the audio profile for, say, Czech is much softer.
- Some languages tend to have phonemes that are nearly indistinguishable from each other to anyone but a native speaker, (think N and M), so a computer is going to have similar difficulties to foreign speakers.

Field trials with users of the ENABLE wrist unit device and the ASR system are being conducted in the UK, Belgium, Austria and the Czech Republic during July and August 2010.

7. DISCUSSION AND CONCLUSIONS

Automatic Speech Recognition is a highly complex task and is not quick and easy to implement, even with the assistance of a speech engine. The ENABLE ASR system supports multiple languages, runs reliably on a mobile device, and uses direct command words and short cuts expected of an easy to use device. The system, when delivered to a typical user, will work "out of the box" and not require any training. The system is targeted at elderly people, whose voices have been used to produce the current speech models. This will be common across all of the defined languages.

The framework for further language development and for impeded speech recognition has also been developed. It is also planned to use the ASR components of the ENABLE system as the basis for a number of further research projects linked to speech recognition; web-based browsing; and ASR for the deaf community; as well as ASR recognition in different contexts. We will also make the new language recognition models available to the wider ASR community (UK, EU and beyond)

Acknowledgements: The ENABLE Project (2007-2010) is funded in part by the European Commission in the 6th Framework Programme (project number: 045 563). Partners are: AT: fortec - Vienna University of Technology – IS, KII - Kompetenznetzwerk Informationstechnologie zur Förderung der Integration von Menschen mit Behinderungen; ES: ARTEC; UK: Docobo Ltd, Cardionetics Ltd., Reading University; CZ: Zivot 90; SP: Code Factory Ltd.; GR: E-Isotis, BE: Vzw Cassiers Wzc; Website *http://www.enable-project.eu*/.

8. REFERENCES

Agent-DYSL (2009), Accomodative Intelligent Educational Interfaces for Dyslexic Learners, http://www.agent-dysl.eu/

Brno University of Technology (2010), Speech Processing Group**,** http://speech.fit.vutbr.cz/

M Cavazza, Companions, Intelligent, persistent, Personalised, Multimodal Interface to the Internet, http://www.companions-project.org/

CMU (2010), Sphinx, http://cmusphinx.sourceforge.net/

Cognifit Limited (2005), Vital Mind, http://cordis.europa.eu/fetch?CALLER=PROJ_ICT&ACTION=D&CAT=PROJ&RCN=85774

ESAT (2010), ESAT PSI Speech Group, http://www.esat.kuleuven.be/psi/spraak/

Google (2010), Google mobile app, http://www.google.com/mobile/google-mobile-app/

M Hawley (2003), STARDUST - Speech Training and Recognition for Dysarthric Users of Assistive Technology, http://www.fastuk.org/research/projview.php?id=216

HTK (2010), Hidden markov model toolkit, http://htk.eng.cam.ac.uk/

INSPIRE (2004), INfotainment management with SPeech interaction via REmote-microphones and telephone interfaces, http://www.ist-world.org/ProjectDetails.aspx?ProjectId=578d8793b1404521ab29a62b1ae55108

J Jiang, A Geven, B Zhang (2009), Hermes - Computer-Aided Memory Management Via Intelligent Computations http://www.springerlink.com/content/t6u276605n5h6v1h/

©2010 ICDVRAT; ISBN 978 07049 15022

Loquendo (2010), Loquendo ASR, http://www.loquendo.com/

Lumenox (2010), Lumenox speech engine, http://www.lumenvox.com/

Luna (2009), Spoken language understanding in multilingual communication systems, *http://www.ist-luna.eu/index.htm*

MJC2 Limited (2007), PAST, experiencing archaeology through space and time, http://cordis.europa.eu/fetch?CALLER=PROJ_ICT&ACTION=D&CAT=PROJ&RCN=52653

Nuance (2010), Nuance speech solutions, http://www.nuance.co.uk/

Nuance (2010), Dictate Medical, HTTP://www.dragon-medical-transcription.com/

Patras (2010), Wire Communications Laboratory, http://www.wcl.ece.upatras.gr/

Patras (2010), A Dialogue System for Telephone-based Services, http://www.wcl.ece.upatras.gr/ai

Philips (2007), Amigo, Ambient Intelligence for the networked home environment, http://www.hitech-projects.com/euprojects/amigo/project_information.htm

J Reiss (2008) EASAIER, prototype on speech and music retrieval systems with vocal query interface http://www.elec.qmul.ac.uk/easaier/publicdeliverables/d3_2_speechmusicprototype_v19%20(2).pdf

Z Rivlin, D Appelt, R Bolles et al (2000), Maestro, conductor of multimedia technologies, http://www-speech.sri.com/projects/sieve/Maestro.pdf

SPEECON (2000), Speech Driven Interfaces for Consumer Devices, http://www.speechdat.org/speecon/index.html

Speechtotext (2010), simon Speech Recognition software, http://sourceforge.net/projects/speech2text/

Synface (2004), Synface, http://www.speech.kth.se/synface/index.htm

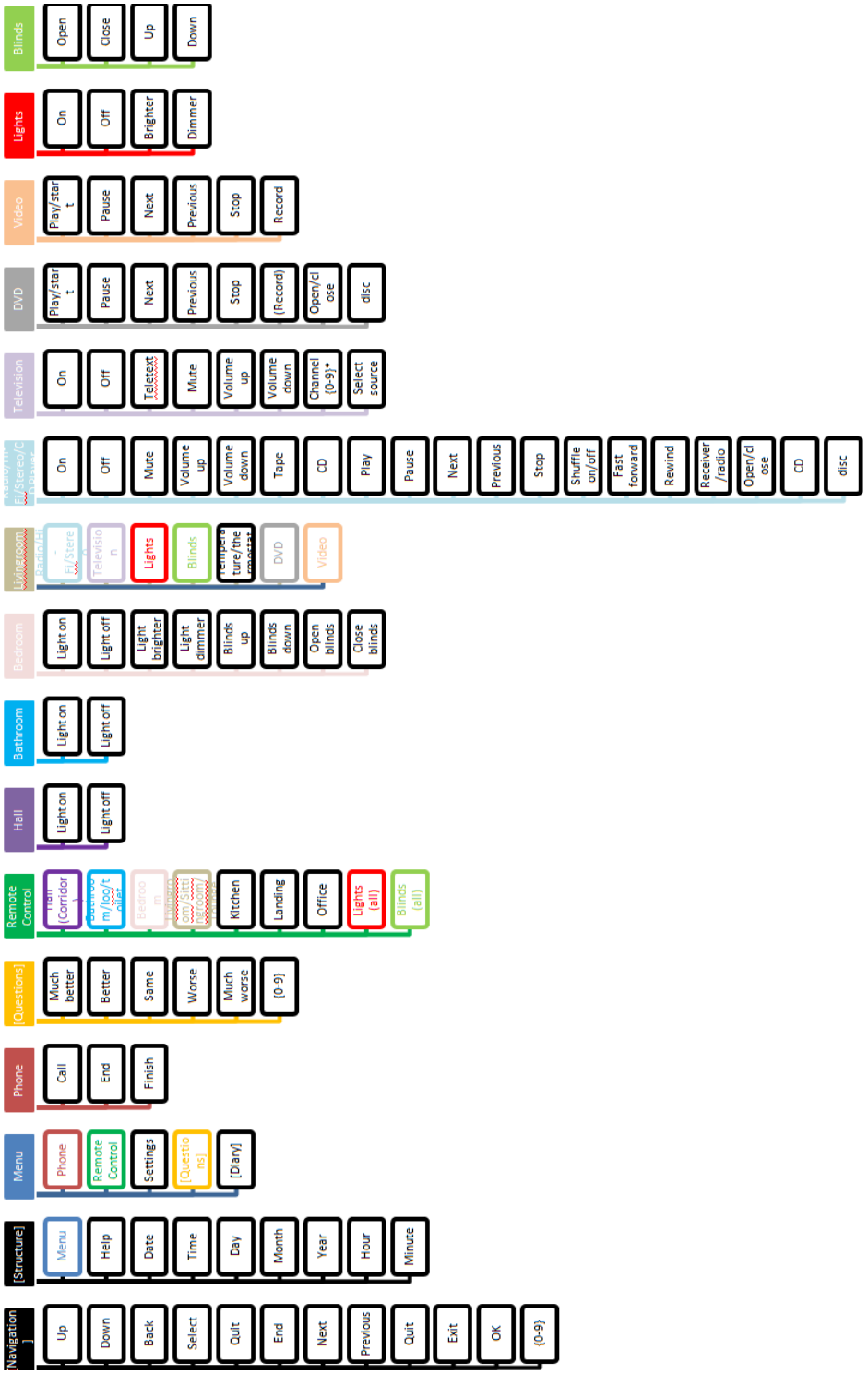


Figure 1. *ASR Command Structure Implemented on the WU.*

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaíso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

Basic study toward automatic generation of glove-type command input device with optimal number of sensors

Y Tabata[1], T Kuroda[2], K Okamoto[3]

[1]Department of Radiation Technology, Kyoto College of Medical Science,
1-3 Imakita, Oyama-higashi, Sonobe, Nantan, JAPAN

[2,3]Department of Medical Informatics, Kyoto University Hospital,
54 Kawahara-cho, Shogo-in, Sakyo-ku, Kyoto, JAPAN

[1]yoshi-t@kyoto-msc.jp, [2]tomo@kuhp.kyoto-u.ac.jp, [3]kazuya@kuhp.kyoto-u.ac.jp

[1]www.kyoto-msc.jp, [2,3]www.kuhp.kyoto-u.ac.jp

ABSTRACT

Data-gloves are one of the most essential devices for VR systems. Although most of conventional data-gloves are designed to capture "analogue" hand postures, most of information systems require just "digital" hand postures corresponding to commands. This paper proposed a method to calculate a data-glove with optimal number of sensors to obtain given set of "digital" hand postures. The authors applied the proposed method to JSL. The result tells that a data-glove with just eight sensors can obtain all hand postures given in JSL.

1. INTRODUCTION

The glove-type input device (data-glove), which can measure hand postures, is one of the most essential devices to develop virtual reality (VR) environments (Dipietro et al, 2008). Although, most of foregoing data-gloves are designed to capture hand postures as they are, most of information systems quantize obtained hand postures to know user's intention as commands. For example, the first VR development environment RB2 maps several certain hand postures to several commands such as "go forward" or "go backward". Sign language translators are other typical example. Except for pure motion capture systems, no information system requires "analogue" hand posture.

The authors have developed a data-glove named "StrinGlove" (Kuroda et al, 2004), which can quantize given postures into a set of notation codes by itself. However, as the authors designed StrinGlove referring to conventional data-gloves, StrinGlove doesn't have enough sensors to capture certain hand postures given in sign languages. On the other hand, StrinGlove seems overengineered device for certain applications, such as VR CAD. As prices of data-gloves are defined simply by number of sensors in many cases, a data-glove should be designed with minimum number of sensors to distinguish a set of "digital" hand postures required for the targeting application.

This paper proposes a method to provide optimal number of sensors to distinguish a given set of "digital" hand postures.

2. RELATED WORKS

2.1 Data-gloves

Hand is most common output device of human beings to manipulate external space directly. Therefore, the many foregoing researches have been trying to emerge direct manipulation environment using human hand. Although several researches such as Iwai et al (1996) and Wang and Popović (2009) tried to obtain hand postures from their outlook, most of researches developed sensor unit to be put on. Such sensor unit, commonly called data-gloves, are widely known as one of the three indispensable devices for VR.

After invention of VPL Dataglove (Zimmerman et al, 1982), many data-gloves have been developed. As most researches assume that combinations of joint angles emerges any hand postures, most of data-glove measures joint angles by various sensors, such as optical-fibers, piezo-registers, carbon ink, etc. However, as motions around metacarpal joints (MPJ) and trapeziometacarpal joint (TMJ) is far more complicated from

©2010 ICDVRAT; ISBN 978 07049 15022

common hand joint model shown in Figure 1, no existing data-glove can obtain detailed hand posture as it is, even they are designed to do so. Some data-gloves like Pinch Glove equip sensors to obtain contact of fingertips. LaViola (1999) claimed that a glove with only contact sensors could obtain over 1000 postures.

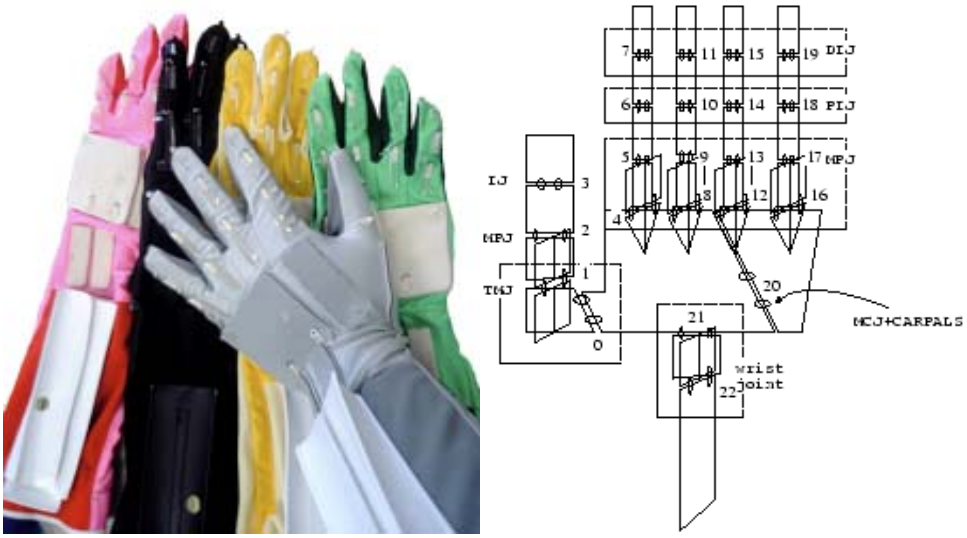


Figure 1. *StrinGlove® (left) and its joint model (right)*

Although some applications, such as motion capture for animations or motor skill evaluation for rehabilitation requires "analogue" hand posture as it is, most of applications intend to obtain "digital" hand posture as a command as the first VR development environment RB2. New data-glove applications, such as wearable computers or motion-based games, also quantize given hand postures into a set of command words. Sign language translators are other typical and conventional example. According to the review by Dipietro et al (2008), most of conventional and new applications of data-gloves can be replaced by keyboards and mice, that is command input devices and pointing devices. Augmented Reality based input systems, such as HIT-wear (Sasaki et al, 2006) and SixthSense (Mistry and Maes 2009), give another typical hand-gesture-based input interface to obtain commands.

2.2 Sign Notations

Sign language is a group of most sophisticated coding system of human motion. Thus, we may refer sign notation codes as a "gold standard" of hand posture.

Foregoing researches tried to develop sign notation systems. Stokoe et al (1965) is the first and most well known trial to define phoneme of sign languages. They claimed that phoneme of any sign languages consisted of "Tab" (location), "Dez" (hand posture) and "Sig" (movement), and denoted each identical element by their original characters. Thus, as each hand posture is denoted by a single notation character, to know detailed posture of each finger from the notation code is rather difficult. Many following researches either simply used the Stokoe's notation characters or invented their own characters as SignWriting (Sutton, 2009) did.

On the other hand, HamNoSys (Hanke 2004) and researches on non-verbal or motion-based human computer interaction, such as Kurokawa (1992), denoted hand posture as a set of finger postures. These systems denote a hand posture as a combination of contacts of fingers and bending angles of each joint.

As most of foregoing notation systems classifies hand posture from subjective point of view, the notations must reflect human perception of hand posture. Thus, the detailed analysis of the notations may give good insights of human perception model. An analysis tells that most of notation systems classify bending angle of each joint into three levels (full bend, weak bend, and stretch). This finding also agrees conventional pathological insights. As two muscles sandwiching the joint controls the joints, the three postures can be encoded as combination of statuses (relaxation and contractions) of the muscles.

3. FINDING MINIMUM REQUIRED SENSORS

3.1 Overview of proposed method

As discussed in 2.2, human hand posture intentionally given can be denoted as combination of rough bending

©2010 ICDVRAT; ISBN 978 07049 15022

angles and contacts between fingers. Therefore, a data-glove equips a contact sensor on each segment of fingers and bending sensors on each joint as shown in Figure 2 could obtain any "digital" hand postures. Here, the contact sensors are not simple switches or pressure sensors to know whether a sensor pressed by another (anonymous) segment, but coupling sensors to tell which (identified) segment touches the sensor. For example, StrinGlove (Kuroda, 2004) equips coupling sensors, consists of small coils to emit wireless signal to give identifier and small coils to receive the identifier on fingertips

However, a single application may not require whole hand posture human beings can express; an application may need a set of certain selected postures. For example, a sign language (like ASL or Japanese Sign Language (JSL)) uses only limited number of hand postures. A set of required hand postures would define a set of required sensors.

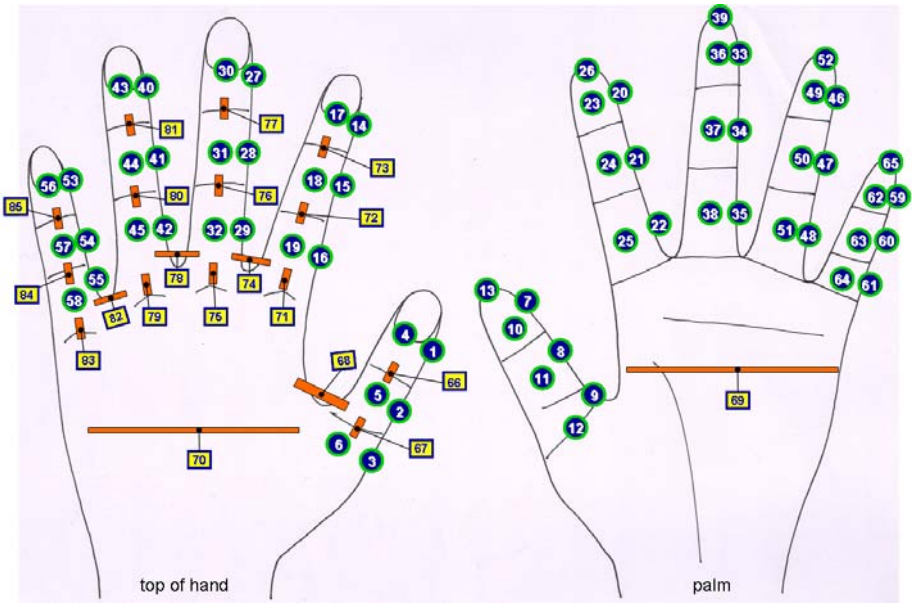


Figure 2. *Sensor Arrangement of Fully Furnished Data-glove*

Once fully furnished data-glove is given, a hand posture (code) can be denoted as a set of sensor values (code-sensor relation table). When two identical codes are given, the difference between given two sets of sensor values tells which sensor is indispensable to distinguish given two hand postures. Thus, the problem to find a set with minimum number of indispensable sensors for a given set of codes must be reduced into a mathematical problem to find a set with minimum number of items to cover given universe, widely known as set-cover problem. The following sections give details of the method.

3.2 Creating Code-Sensor Relation Table

The fully furnished data-glove given in Figure 2 equips 85 sensors; 65 contact sensors (no.1 to 65) and 20 bending sensors (no. 66 to 85). As each contact sensor is a coupling sensor, sensor output becomes multi-value data consists of status of contact (0: non-contact, 1: contact) and an ID of touching sensor. On the other hand, output of bending sensor is status of bending angle (0: full-stretch, 1: weak-bend, 2: full-bend).

Under above discussed notation system, each hand posture (code) of a given set is denoted as a set of 85 sensor values of the data-glove as shown in Table 1. When we plot only statuses of contacts and bending angles, Table 1 becomes Table 2. Here, Table 2 actually provides a set of sensor output when the contact sensors are simple switches. Therefore, when all row of Table 2 is distinct, the given set of codes can be distinguished by a glove equips simple switches instead of coupling sensors. Table 2 tells that a data-glove equips simple switches can distinguish case A not case B.

3.3 Reduction to the Set Cover Problem

If all the codes are not identified with simple switches, a brute-force method seems required because the relation between the number of selected sensors and a set of distinguishable codes is complicated. On the other hand, if all the codes are identified with simple switches, we can reduce the proposed optimizing problem to the set cover problem. Then, the problem can be solved via algorithms for the set cover problem.

The set cover problem is one of the most famous NP-complete problems (Karp, 1972). An instance (U, V) of the set cover problem consists of a set U of n elements and of a set $V=\{V_1, \ldots, V_m\}$ where $V_1, \ldots, V_m$ are

©2010 ICDVRAT; ISBN 978 07049 15022

subsets of U. The set cover problem is to find the minimum collection of subsets $V'(\subseteq V)$ whose union is equal to U. Since the set cover problem is NP-complete, it is hard to solve it in polynomial time. We can refer a brute-force algorithm and a dynamic programming algorithm as exponential time algorithms to solve the problem though there is unfortunately much fewer studies on exponential time algorithms than on approximation algorithms (Johnson, 1974; Lovász, 1975; Slavík, 1997; Feige, 1998; Goldschmidt, 1993).

Table1. *Code-Sensor Relation Table (with coupling sensors)*

Case A

| No. | hand shape (example) | sensor number | | | | | | | | | | | | | sensor number | | | | | | | | | | | | |

The second step is to make an instance (U, V) of the set cover problem. Each pair of codes is regarded as an element of U, and the subset of pairs in which a certain sensor's value is 1 is regarded as an element of V. For example, in Table 3, as the sensor no.17 distinguishes code α and β (the pair no.1) and code α and γ (the pair no.2), the set of pairs {1, 2}, namely V_{17}, becomes an element of V. The subset corresponds to a group of code pairs that can be distinguished by a single sensor no.17. The reduction from the proposed problem to the set cover problem is complete because finding the minimum collection of subsets $V'(\subseteq V)$ whose union is U equals to finding the sensors of the minimum number which distinguish all the pairs of codes. For example, in Table 3, the answer is $\{V_{17}, V_{26}\}$, $\{V_{17}, V_{29}\}$ or $\{V_{26}, V_{29}\}$.

3.5 Solving the Set Cover Problem

Exact algorithms for the set cover problem take exponential time to solve an instance. The more subsets of an instance there are, the more run-time increases. Therefore, it is important to decrease the solution space of an instance. The first step of the preprocessing to decrease the solution space is to omit some sensors, whose corresponding columns do not include 1s, i.e., these sensors are not contributing. The second step of the preprocessing is to omit sensors whose corresponding columns are identical to another sensor, i.e., these sensors are replaceable.

The third step, the main procedure, is to solve the reduced instance using the exponential time algorithms. If the exponential time algorithm cannot solve it in realistic time, approximation algorithms are applied. If $P \neq NP$, the worst-case approximation ratios of approximation algorithms are known as θ (log m) (m is the number of subsets) (Johnson, 1974; Lovász, 1975; Raz, 1997), which means that a solution of the approximation algorithms can be O (log m) times as large as the optimal solutions. However, the approximation ratio is close to 1 experimentally (Gomesa, 2006).

4. EVALUATIONS

4.1 Target dataset

The authors selected JSL as a source of target dataset. Takemura (1999) and Kanda (2010) examined hand postures given in JSL and found that 50 hand postures shown in Figure 3 can express at least 600 JSL words. Thus the authors selected the 50 hand postures as a target dataset. Another target dataset is 28 hand postures surrounded by dotted line, which are shown in Japanese finger characters.

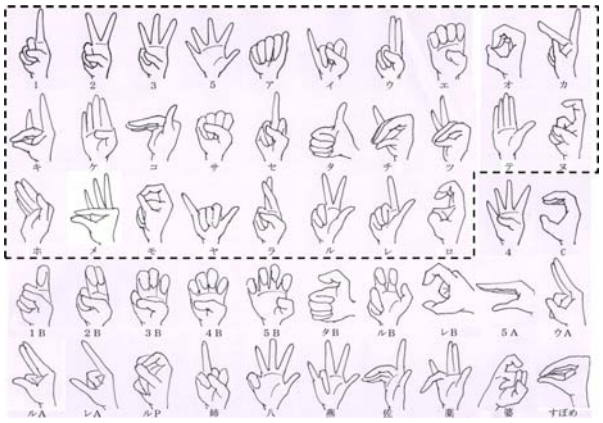


Figure 3. *50 hand shapes of JSL and their notation codes.*

4.2 Result

At first, the authors developed code-sensor relation tables of JSL and Japanese finger spelling. Table 4 shows the code-sensor relation table of Japanese finger spelling. Recall that sensors from No.1 to No.65 are contact sensors and sensors from No.66 to No.85 are bending sensors.

As all the rows of both tables were distinct, the authors picked only contact status of contact sensors and constructed pairwise code-sensor relation tables. The preprocessing to omit non-contributing sensors omitted 34 sensors in the case of JSL and 35 sensors in the case of Japanese finger characters. The second step to omit replaceable sensors omitted 10 sensors in JSL and 11 sensors in Japanese finger characters.

After preprocessing, the authors tried to solve the reduced instances of set cover problem using an exponential time algorithm that takes a great deal of time. However, the authors could get optimal solutions in both cases because the solution space was relatively small. The minimum number of sensors to distinguish all the codes in JSL is eight and there are 133 combinations. On the other hand, the minimum number of

©2010 ICDVRAT; ISBN 978 07049 15022

sensors to distinguish all the codes in Japanese finger character is six and there are just 2 combinations; $\{V_{35}, V_{66}, V_{68}, V_{72}, V_{74}, V_{85}\}$ and $\{V_{35}, V_{67}, V_{68}, V_{72}, V_{74}, V_{85}\}$.

Table 4. *The code-sensor relation table of Japanese finger characters.*

No.	hand shape of notaion code	sensor number																
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	…	85
1	1	0	0	0	0	0	0	0	0	0	1(30)	0	0	0	0	0		2
2	2	0	0	0	0	0	0	0	0	0	1(43)	0	0	0	0	0		2
3	3	0	0	0	0	0	0	0	0	0	1(56)	0	0	0	0	0		1
4	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
5	ア	0	0	0	0	0	0	0	0	0	1(16)	0	0	0	0	0		2
6	イ	0	0	0	0	0	0	0	0	0	1(30)	0	0	0	0	0		0
7	ウ	0	0	0	0	0	0	0	0	0	1(43)	0	0	0	0	0		2
8	エ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		2
9	オ	0	0	0	0	0	0	1(26)	0	0	0	0	0	1(39)	0	0		1
10	カ	0	0	0	0	0	0	0	0	0	1(37)	0	0	0	0	0		0
11	キ	0	0	0	0	0	0	0	0	0	1(36)	0	0	0	0	0		0
12	ケ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
13	コ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
14	サ	0	0	0	0	0	0	0	0	0	1(43)	0	0	0	0	0	…	2
15	セ	0	0	0	0	0	0	0	0	0	1(43)	1(17)	0	0	0	0		1
16	タ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		2
17	チ	0	0	0	0	0	0	1(23)	0	0	1(36)	0	0	0	0	0		0
18	ツ	0	0	0	0	0	0	1(23)	0	0	1(36)	0	0	0	0	0		0
19	テ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
20	ヌ	0	0	0	0	0	0	0	0	0	1(43)	0	0	0	0	0		2
21	ホ	0	0	0	0	0	0	0	0	0	1(16)	0	0	0	0	0		1
22	メ	0	0	0	0	0	0	0	0	0	1(23)	0	0	0	0	0		1
23	モ	0	0	0	0	0	0	0	0	0	1(23)	0	0	0	0	0		1
24	ヤ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		0
25	ラ	0	0	0	0	0	0	0	0	0	1(43)	0	0	0	0	0		1
26	ル	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1
27	レ	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0		1
28	ロ	0	0	0	0	0	0	0	0	0	1(43)	0	0	0	0	0		1

4.3 Discussions

The dramatic decrease of required sensors for JSL and Japanese sign characters indicates that the proposed method is capable as the method to select indispensable sensors.

There were 133 sets of minimum numbers of sensors to distinguish JSL. The best one out of 133 set may be defined from prices of sensors, manpower to mounting sensors on glove, and favor of users. Although waited set-patter problem seems applicable, the parameters to determine the weight of each sensors, such as required manpower, are not independent each other. Manual process to select a best set according to given criteria may be required.

The sensor no.73 is in all 133 sets. The fact means the sensor is indispensable to distinguish 50 hand postures given in JSL. The detailed analysis clears that the sensor is the bending sensor to measure angle of distal interphalangeal joint (DIJ) of index finger and is indispensable to distinguish two hand postures shown in Figure 4. Most of conventional data-gloves don't equip a sensor to measure bending of DIJ under a hypothesis that angle of DIJ is always proportional to angle of proximal interphalangeal joint (PIJ) and that DIJ is not important to get hand postures. The result denies the hypothesis of foregoing data-gloves. The fact clearly confirms the effectiveness of the proposed method.

Figure 4. *Hand postures distinguished by the sensor no. 73.*

In this research, the authors start from a code-sensor relation table where a single code defined as a single combination of sensor values. However, the "digital" hand posture cannot be always defined as a specific combination of sensor values. Subjective definition of hand posture cannot be so rigid. To accept variations for each code, we need to develop several rows for a certain code in code-sensor relation table. Although we need to omit rows of pair of identical codes on the pairwise code-sensor relation table, the same proposed algorithm will provide sets of optimum number of sensors for a given set of codes.

©2010 ICDVRAT; ISBN 978 07049 15022

5. CONCLUSIONS

This paper proposed a method to work out a set of minimum number of indispensable sensors to distinguish a given set of hand postures by reducing the problem into simple set-cover problem. The developed method clears that a data-glove to distinguish JSL requires only eight sensors, and a data-glove to distinguish Japanese finger characters requires only six sensors. The developed method enables us not only to produce low-cost data-gloves for each use cases, but also to discuss the communication bandwidth of gesture communication of human beings.

Acknowledgements: The authors would like to thank Dr. Shinobu Kawagishi of Sakai City Office and Prof. Kazuyuki Kanda of Chukyo University for their support for defining hand posture set of JSL. The authors also would like to thank Teiken Limited, Fujita Corp. and AMITEQ Corp. for their continuous support to develop StrinGlove®.

6. REFERENCES

L. Dipietro, A.M. Sabatini and P. Dario (2009), A Survey of Glove Based Systems and Their Applications, *IEEE Trans. Man. Cyber.,* **38**, *4*, pp.461-482.

O. Goldschmidt, D. S. Hochbaum and G. Yu (1993) A Modified Greedy Heuristic for the Set Covering Problem with Improved Worst Case Bound, *Info. Proc. Lett.*, **48**, pp.305-310.

F.C. Gomesa, C.N. Menesesb, P.M. Pardalosb and G.V.R. Viana (2006) Experimental Analysis of Approximation Algorithms for the Vertex Cover and Set Covering Problems, *Comp. & Ope. Res.*, **33-12**, pp.3520-3534.

T Hanke (2004) HamNoSys - Representing Sign Language Data in Language Resources and Language Processing Contexts, *Proc. LREC*, pp.1-6.

Y. Iwai, K. Watanabe, Y. Yagi and M. Yachida (1996) Gesture Recognition using Colored Gloves, *Proc. ICPR*, **1**, pp.662-666.

D.S. Johnson (1974) Approximation Algorithms for Combinatorial Problems, *J. Comp. Sys. Sci.*, **9**, pp.256-278.

K.Kanda (2010), *A Study of Linguistic Characteristics of Japanese Sign Language*, Fukumura Press, Tokyo, *Japanese*.

R.M. Karp (1972) Reducibility Among Combinatorial Problems, In *Complexity of Computer Computations* (R. E. Miller and J. W. Thatcher, Eds.), Plenum Press, New York, pp. 85-103.

T. Kuroda, Y. Tabata, A. Goto, H. Ikuta and M. Murakami (2004) Consumer Price Data-Glove for Sign Language Recognition, *Proc. ICDVRAT*, pp.253-258.

T. Kurokawa (1992) Gesture Coding and a Gesture Dictionary for a Nonverbal Interface, *IEICE Trans. Fund. Elect.*, **75**, pp.112-121.

J.J. LaViola (1999) A Survey of Hand Posture and Gesture Recognition Techniques and Technology, *Tech. Rep. of Brown Univ.*, CS-99-11.

L. Lovász (1975) On the Ratio of Optimal Integral and Fractional Covers, *Discrete Math.*, **13**, pp.383-390.

P. Mistry and P. Maes (2009) SixthSense – a Wearable Gesture Interface. *Proc. SIGGRAPH Asia*.

R. Raz and S. Safra (1997) A Sub-Constant Error-Probability Low-Degree Test, and Sub-Constant Error-Probability PCP Characterization of NP, *Proc. STOC*, pp.475-484.

H. Sasaki, T. Kuroda, P. Antoniac, Y. Manabe and K. Chihara (2006) Hand-Menu System: a Deviceless Virtual Input Interface for Wearable Computers, *CEAI J.*, **8**, *2*, pp.24-33.

P. Slavík (1997) A Tight Analysis of the Greedy Algorithm for Set Cover, *J. Algo.*, **25**, pp.237-254.

W.C. Stokoe, D.C.Casterline and C.G. Croneberg (1965) *A Dictionary of American Sign Language on Linguistic Princeples*, Gallaudet College Press, Washington DC.

V. Sutton (2009) *SignWriting*, The SignWriting Press, Lo Jolla.

S.Takemura(1999), *Shuwa-Nihongo-Daijiten*, Kosaido Press, Tokyo, *Japanese*.

R.Y. Wang and J. Popović (2009), Real-Time Hand-Tracking with a Color Glove, *Proc. SIGGRAPH*, **28-3**, p.*63*.

T.G. Zimmerman, J. Lanier, C. Blanchard, S. Bryson and Y. Harvill (1987) A Hand Gesture Interface Device, *Proc. SIGCHI*, pp.189-192.

©2010 ICDVRAT; ISBN 978 07049 15022

Virtual environments for exposure in Obsessive-Compulsive Disorder

G Cárdenas-López, S Muñoz

Laboratorio de Enseñanza Virtual y Ciberpsicología, Facultad de Psicología, UNAM, MÉXICO, DF

cardenas.georgina@gmail.com, simm_psic@yahoo.com.mx

Abstract — **Obsessive Compulsive Disorder (OCD) affects 2.6% of the population in Mexico, severely affecting the quality of life of the people who suffer it. The World Health Organization (WHO) ranks OCD as the tenth leading cause of disability in the world, representing a health issue that requires attention, especially from health professionals. Several studies on the different treatments developed for this disorder have been carried, including: exposure, response prevention and cognitive therapy. We developed a treatment based on virtual reality (VR) technologies to expose patients with OCD to controlled virtual environments. The treatment includes sessions of psychoeducation, breathing training, cognitive restructuring and exposure, using a Head Mounted Display (HMD). VR increases the sense of immersion and presence in the environment, and evokes the same reactions and emotions that are experienced in real situations.**

1. Introduction

People with OCD develop excessive fears of situations that are not truly dangerous. The obsessions involved can be a variety of thoughts, images or impulses and the compulsions can involve any number of repeated actions or thinking patterns. Among the many types of obsessions and compulsions, highlights: contamination obsessions (bodily waste or secretions, dirt or germs, environmental contaminants, insects, becoming ill from contamination), contamination compulsions (cleaning of the house, cleaning of objects, avoidance of objects considered "contaminated"), ordering obsessions (preoccupation with symmetry, exactness or order, concern with aligning papers, books) and ordering compulsions (counting items, books, arranging items in a certain order).

The use of this technology is based on the non direct exposure of the subjects to feared situations, which could result to be costly, inconvenient or inaccessible considering certain circumstances. Using virtual environments that simulate real situations we reduced the aversion of the patients. Most research has focused on anxiety disorders, but this have centred in the virtual reality treatment for eating disorders, addictions, psychological assessment, pain management, palliative care, some impulse control disorders and rehabilitation (Clark et al, 1998, Kirkby et al, 2000).

For OCD there are few studies conducted based in information technologies (Krijn et al, 2004; North et al, 1998; Van den Hout, 2003). One example is the study of Clark (1998) in which behavioural experiments were conducted in virtual reality with a specific focus on the behaviour of compulsive washing. The results of this study were moderately satisfactory and the authors raised the possibility of seeing the behavioural experiments with virtual reality as an initial evaluation or previous training for the treatment and that this don´t necessarily replaces traditional therapy based on in vivo exposure and response prevention.

II. Virtual Exposure For OCD

Because the prevalence of OCD in Mexico, we proposed to develop a treatment protocol and virtual reality environments for two kinds of obsession and compulsions: Contamination Obsessions and Ordering obsessions. This type of intervention aims to reduce the anxiety and dislike that produces a treatment based on exposure and traditional response prevention. The treatment supported by virtual reality exposes the patients to their obsessive triggering fears in tridimensional computer environments.

III. Virtual Environments

The bus is considered a scenario in which people must interact with the elements that compose it, such as people and elements inherent to this space. To bring some obsessive fears, this scenario often has aversive stimuli for OCD patients with contamination obsessions; such stimuli are associated with dirt on the seats, grab tubes from the floor, contact with dirty or untidy persons or apparently suffering from some illness, which patients perceive as an important source of infection.

The traditional restaurant represents an ideal scenario to work with obsessions of contamination because the persons with OCD can't be sure of the

©2010 ICDVRAT; ISBN 978 07049 15022

conditions in which their food is prepared in relation to hygiene and handling by other persons or the provenance of the ingredients of the prepared dishes, concern of the neatness of other elements of the place (dishes, cutlery, trays, tables, chairs, telephones, floor) because of the regular use that many people do of this. Likewise contains elements that can help work with the obsessions of order, symmetry, incompleteness and accuracy that cause anxiety, distress or discomfort in the patients, such as sauces, salt shakers, mugs and napkins among others.

Figure 1. *Virtual restaurant for contamination obsessions.*

The room is composed of a bed (with sheets, blankets, quilts, rollers), a bookseller (with TV, books), a desktop (with office work items such as pens notebooks, sheets), comfortable with diverse Articles in (medicine, magazines, etc..) and a wardrobe (with clothes, shoes and other accessories inside). It is a space in which the patient may be exposed to various degrees of disorder of the aforementioned elements, as well as potential pollution stains, dust, besides being a place that refers to their daily lives.

Figure 2. *Virtual room for order obsessions.*

The public restroom represents one of the most feared by people with obsessions of contamination to be considered as a potential source of disease, by the constant use that people make of it, where dirt may be largely perceived in body fluids that are perceived as unpleasant, dirty and transistors of various kinds of diseases. All elements of the site are intended to cause discomfort or anxiety in the patient by the possible pollution arising from this stimulus.

Figure 3. *Virtual environment of rest room.*

Table 1. *Patient and therapist Interaction.*

Environment	Patient	Therapist
Bus	Navigate Interact with objects Order some objects	Cleaning level
Public restroom		
Restaurant		Order level cleaning level men and women selection trigger event related with the obsessions (conversations, animals, tv and radio news)
Room		

IV. METHOD

The study (still in process) establishes as goal the evaluation of usability and user´s preferences of virtual reality environments for OCD. In this paper, we present results of a sample of 30 college students who voluntarily participated in the study, providing informed consent. The aim of the study was to expose participants to virtual environments for OCD treatment in a desktop computer with a head mounted display with integrated head-tracker Vuzyx ® VR920 and using a joystick for the navigation. Participants were exposed to the five scenarios developed to assess RV rates Presence and usability preferences of the participants. The assessment tools used report variables measured by indicators of anxiety such as galvanic skin response, temperature and heart rate frequencies as well as the self-report of Presence and Reality Judgement (Baños et al. 2006).

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaiso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

V. CONCLUSIONS

The introduction of new technologies to psychological treatments has been successfully proven in several studies. However in the case of OCD, there are few researches using this technology. Virtual environments could provide clinical important advantages, such as reducing the patient anxiety and aversion, increase the control of the environment and gradually exposure to obsessive triggering fears to each patient. Data will provide us of an empirical base to adjust and disseminate the innovative treatment protocol.

REFERENCES

Clark, A., Kirkby, K.C., Daniels, B.A., Marks, I. M. (1998). A pilot study of computer-aided vicarious exposure for obsessive-compulsive disorder. Australian and New Zealand Journal of Psychiatry, 32, 268-275.

Kirkby, K. C., Berrios, G. E., Daniels, R. G., Menzies, R. G., Clark, A., & Romano, A. (2000). Process-Outcome Analysis in Computer- Aided Treatment of Obsessive-Compulsive Disorder. Comprehensive Psychiatry, 41(4), 259-265.

Krijn, M., Emmelkamp, P., Olafsson, R. P., & Biemond, R. (2004). Virtual reality exposure therapy of anxiety disorders: A review. Clinical Psychology Review, 24, 259-281.

North, M. M., North, S. M., & Coble, J. R. (1998). Virtual reeality therapy. An effective treatment for phobias. In G. Riva, B. Wiederhold & E. Molinari (Eds.), Virtual environments in clinical psychology and neuroscience. Amsterdam: IOS Press.

Van den Hout, M. K. M. (2003). Repeated checking causes memory distrust. Research and Therapy, 41(3), 301-316.

Van den Hout, M. K. M. (2004). Obsessive-compulsive disorder and the paradoxical effects of perseverative behaviour on experienced uncertainty. Journal of Behavior Therapy, 35(2004), 165-181.

©2010 ICDVRAT; ISBN 978 07049 15022

An integrative approach for designing collaborative technologies for social competence training in children with autism spectrum conditions

S V Cobb, L Millen, T Glover

VIRART, Human Factors Group,
University of Nottingham,
Nottingham, UK

{sue.cobb, emxlm, tony.glover}@nottingham.ac.uk

S Parsons, S Garib-Penna

School of Education
University of Birmingham,
Birmingham, UK

{s.j.parsons, s.garibpenna}@bham.ac.uk

P L Weiss, E Gal

Department of Occupational Therapy
University of Haifa, ISRAEL

tamar@research.haifa.ac.il, eynatgal@gmail.com

N Bauminger, S Eden

School of Education, Bar Ilan University
Tel Aviv, ISRAEL

bauminn@mail.biu.ac.il,ueden@upp.co.il

M Zancanaro, L Giusti

i3 Research Unit
FBK, Trento, ITALY

zancana@fbk.eu, giusti@fbk.eu

Abstract — **The COSPATIAL project is exploring the use of two collaborative interaction technologies, Collaborative Virtual Environments (CVEs) and Shared Active Surfaces (SASs), as suitable media to support learning of social competence skills for typically developing children and those with Autism Spectrum Conditions (ASC)s. This paper describes the integrated approach used to design and develop learning scenarios in each technology.**

I. Technology And Autism

It is known that computing technology is particularly appealing to children with autism (Barry & Pitt, 2006) and may be uniquely suitable to support them in learning activities. Features of computing technology that may be particularly attractive for learners with ASC include automaticity (enabling tasks to be repeated), provisionality (that errors can be easily corrected), interactivity (providing active engagement) and sociability (to allow collaborative learning) (Hardy et al, 2002).

The COSPATIAL project investigates two categories of technologies for collaborative interaction that have previously demonstrated potential to be both feasible and effective for the social skills training and collaborative interaction for children with high functioning autism; Collaborative Virtual Environments (CVEs) Shared Active Surfaces (SASs). CVEs have been explored as a medium for demonstration and rehearsal of appropriate behaviour in social situation (Cobb et al., 2002). SASs have successfully been used for shared story creation to enhance collaboration (Gal et al., 2009). Thus there are distinct differences between these technologies with regard to how they may be applied to collaborative interaction; specifically CVEs enable distributed collaboration and offer the opportunity for 'perspective-taking' tasks and social communication via the technology; SASs support co-located collaborative interaction and face-to-face social communication that takes place alongside the technology.

II. Principles Of Cognitive Behaviour Therapy (CBT)

A range of social cognitive capabilities such as; adequate interpersonal problem solving, accurate processing of information, social perception and perspective taking, together with range of behavioural capabilities such as; developing appropriate social interaction with peers (including social conversation and cooperative skills), are required for appropriate social functioning. CBT offers a multimodal framework that takes into account cognition and behaviour for guiding intervention efforts. Several studies have focused on the enhancement of social and emotional understanding and promoting social cognitive capabilities such as theory of mind, emotion recognition, and the understanding of social

©2010 ICDVRAT; ISBN 978 07049 15022

scenarios through CBT techniques using, for example, social stories (Delano & Shell, 2006) or role play (Spence, 2003). Studies that have implemented an integrative model of CBT which included both cognitive as well as behavioural techniques seem to yield promising outcomes in social functioning for children with ASC (Hermelin & O'Connor, 1985).

III. Integrated Approach To Technology Development

The objective of COSPATIAL is to develop a framework to guide the design of CBT-inspired technologies to support learning of social competence skills in children with and without autism. An integrated approach to scenario design and technology development is illustrated in Figure 1 depicting the COSPATIAL 'sandwich' metaphor to describe this approach.

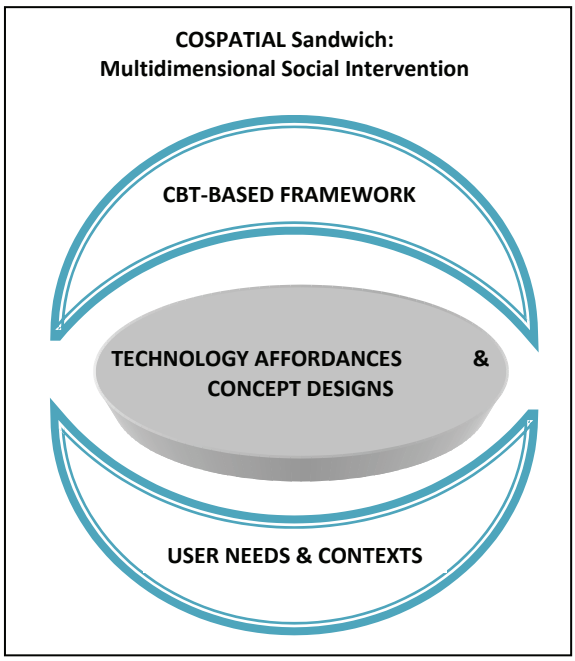


Figure 1. *The COSPATIAL sandwich metaphor for an integrated design approach.*

The sandwich has top and bottom layers with well-matched combinations of fillings inside. Represented as the top layer, the CBT-framework is used to inform scenario design with regard to how to integrate CBT principles into the scenario and how best to offer mediation for student learning. The bottom layer is concerned with understanding user-needs and contexts in which the technology will be implemented. The filling is represented by the affordances of the technologies as well as concept designs and how specific tasks are realised within and around the technology. Our final prototypes, and methods of implementation and evaluation, will only be true to our framework (i.e., make a good sandwich) if we take all of these factors into account. Thus, a purely CBT-driven (top-down only); or user-needs driven (bottom-up) or technology-driven (the 'filling') approach will not suffice – the final prototypes must take into account all layers, and how well they are matched with each other.

The COSPATIAL sandwich ensures that we take a considered approach to the design and development of educational technology and its implementation in different learning environments. This involves a number of factors that influence design and development of the COSPATIAL educational technology for children on the autism spectrum, as shown in Figure 2 and described below.

Figure 2. *Factors to consider when developing educational technology for children on the autism spectrum.*

3.1 Facilitation

The CBT conceptual framework highlights the crucial role of a facilitator or mediator in helping participants to explain and interpret the underlying concepts being taught. By taking a CBT-informed approach to design, we are able to identify the places within each scenario where mediation may be required. Observation of user behaviour and interaction between peer pairs as well as child-facilitator pairs helps to identify how facilitators offer mediation; this is used to inform decisions concerning whether the mediation can be 'built-in' to the program.

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaiso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

3.2 Scaffolded learning

The role of a facilitator is central also to supporting learning, and 'scaffolding' remains an important conceptual as well as pedagogical approach. This involves consideration of who is doing the scaffolding and the context in which this occurs. For example, participants could be paired with an adult mediator or with peers of different functional levels to complete the task; there is good evidence that peer facilitation can have beneficial effects for children with ASC both in terms of learning and self-esteem.

3.3 ICT in context

One of the benefits we anticipate from the COSPATIAL project is that schools will be willing and able to use the information and communication technologies (ICT) and tasks developed. Thus, the legacy of the project is important and consideration needs to be given to this throughout development. It will be necessary, then, to report on both how the chosen technologies fit with existing classroom practice and equipment, as well as how they could be made more accessible in the future e.g., through creating inexpensive multi-touch surfaces using Wii remotes and projectors.

3.4 User-centred design (UCD)

Design for use in school classrooms does not only require technical considerations but also that we ensure that the technology is designed to be fit for the intended purpose of use. Observation of current use of technology in schools identified a need for bespoke software that is designed specifically to suit the usability and learning requirements of educational technology for children with ASC (Leach, 2010). Effective design of educational technology is complex and challenging and a key output of the COSPATIAL project will be a design framework defined through a process of iterative development and review. A UCD approach is applied to help inform and evaluate the framework. It is essential to include teachers as well as representatives of the 'end user' population, i.e., both typically developing children and those with ASC, in design decisions and prototype development and testing throughout. This seeks to ensure a better fit between the concepts and their pedagogical usefulness both in terms of the concepts being learned but also in terms of how the facilitation works; how much the children are engaged/motivated; and how much effort they have to make while using the technology. Pragmatic issues about when/where sessions take place will also be considered.

3.5 Participant groups

It is understood that no one solution will meet the needs of all children on the autism spectrum and so it will be crucial to obtain good information about participants' background characteristics, such as age, verbal ability, IQ, executive functioning and autism characteristics. This will enable the COSPATIAL project to identify for whom the CBT-informed tasks via these two technologies are best targeted. This will also enable us to make recommendations for future applications and their implementation.

3.6 Personalisation

Given the heterogeneity of children with ASC, the ability to personalise at least some aspects of the designs and/or implementation of the CVEs and SAS will be important (Leach, 2010; Davis et al., 2010). The extent to which personalisation will be appropriate or feasible with our chosen technologies is an open question that is being explored throughout the COSPATIAL project.

3.7 Understanding autism

Understanding user needs and requirements is fundamental to effective design of any technology. In this project it is important to focus on the 'core deficits' of autism when targeting psycho-educational approaches; this is true both in terms of the specific skills/understanding being targeted and also in terms of ensuring that outcome measures appropriately measure the anticipated improvements in the targeted skills/understanding. The COSPATIAL project focuses on interaction and communication difficulties in the social domain; specifically, in relation to collaboration and social conversation. Therefore, an important challenge will be to ensure that the developed tasks target these competencies appropriately and that we can sensitively measure and document changes in performance. There is a considerable number and range of behavioural and cognitive scales and tasks that could be utilised and we will need to ensure that our choices are 'fit for purpose'.

IV. CONCLUSIONS

The integrative approach to development of educational technology for children on the autism spectrum applied in COSPATIAL provides a robust conceptual foundation for considering how social competence may be facilitated through the application of innovative new technologies in conjunction with the principles of CBT.

©2010 ICDVRAT; ISBN 978 07049 15022

The main challenge for the COSPATIAL project is to explore whether it is possible for our chosen technologies to support the multidimensional approach to developing social competence as required by CBT. Furthermore, we need to determine how to integrate CBT principles and collaborative technologies (CVE and SAS), and how they can offer an effective educational intervention for children at different points along the autism spectrum. Following on from this, we will also take inspiration from the CBT tenets to stimulate education on social competence for typically developing children (e.g., bullying, multi-cultural issues, etc.) which may constitute a new paradigm for the technology-enhanced learning domain.

ACKNOWLEDGEMENTS

This work is funded under the Seventh Framework Programme of the European Commission (http://cospatial.fbk.eu/).

REFERENCES

Barry, M. & Pitt, I. (2006). Interaction design: a multidimensional approach for learners with autism. *Proceedings of the 2006 conference on Interaction design and children* pp. 33-36

Cobb, S., Beardon, L., Eastgate, R., Glover, T, Kerr, S., Neale, H., Parsons, S., Benford, S., Hopkins, E., Mitchell, P., Reynard, G., & Wilson, JR. (2002). Applied Virtual Environments to support learning of Social Interaction Skills in users with Asperger's Syndrome, *Digital Creativity*, Vol. 13, No.1, 11-22.

Crook, C. (1991). Computers in the zone of proximal development: implications for evaluation. *Computers & Education*, 17, pp 81-91.

Davis, M. Dautenhahn, K., Powell, S.D. & Nehaniv, C.L. (2010) Guidelines for researchers and practitioners designing paper software and software trials for children with autism. *Journal of Assistive Technologies*, 4, pp 38-48.

Delano & Shell (2006). The effects of social stories on the social engagement of children with autism. *Journal of positive Behavior Interventions,8,* 29-42.

Gal, E., Bauminger, N., Goren-Bar, D., Pianesi, F., Stock,O., Zancanaro, M. and Weiss, P.L. (2009). Enhancing social communication of children with high functioning autism through a co-located interface. *Artificial Intelligence & Society*, 24, pp 75–84.

Hardy, C., Ogden, J., Newman, J. & Cooper, S. (2002) *Autism and ICT: A Guide for Teachers and Parents*. London, UK: David Fulton Publishers Ltd.

Hermelin, B., & O'Connor, N. (1985). Logico-affective states and nonverbal language. In E. Schopler, & G. B. Mesibov (Eds.) *Communication problems in autism* (pp. 283–309). New York: Plenum Press.

Leach, C. (2010) The use of smartboards and bespoke software to develop delivery and deliver an inclusive, individual and interactive centred learning curriculum for students with ASC. *Journal of Assistive Technologies*, 4, pp 54-57.

Mitchell, P., Parsons, S. & Leonard, A. (2007) Using virtual environments for teaching social understanding to adolescents with autistic spectrum disorders. *Journal of Autism and Developmental Disorders*, 37, pp 589-600.

Spence, S. H. (2003). Social skills training with children and young people: Theory, evidence and practice. *Child and Adolescent Mental Health*, 8, 84-96

©2010 ICDVRAT; ISBN 978 07049 15022

Videogame for improving orientation and mobility in blind children

J Sánchez, J P Rodríguez

Department of Computer Science and Center for Advanced Research in Education (CARE)
University of Chile, Santiago, CHILE

jsanchez@dcc.uchile.cl, jurodrig@dcc.uchile.cl

Abstract — **This work presents an evaluative study on the usability of a haptic device together with a sound-based videogame for the development and use of orientation and mobility (O&M) skills in closed, unfamiliar spaces by blind, school-aged children. A usability evaluation was implemented for a haptic device especially designed for this study (Digital Clock Carpet) and a 3D videogame (MOVA3D) in order to determine the degree to which the user accepted the device, and the level of the user's satisfaction regarding her interaction with these products for O&M purposes. In addition, a preliminary cognitive evaluation was administered. Usability results show that both the haptic device and the videogame are usable, accepted and considered to be pleasant for use by blind children. The results also show that they are ready to be used for cognitive learning purposes. Results from the preliminary cognitive study demonstrated significant gains in the development of tempo-spatial orientation skills of blind children when navigating in unfamiliar spaces.**

I. Introduction

In order to move around safely in closed spaces, blind people avoid moving through the center of rooms and navigate by touching the walls around the perimeter of the room ("shorelining"). This form of navigation is inefficient. However when a blind person has time to familiarize himself with the environment, he gets more confident and is able to find and navigate more efficient routes (Sánchez and Elías, 2007).

Virtual environments can be used to provide blind people with virtual training exercises that allow them to improve their navigation skills and to later transfer such skills to the real world. The user can create a mental map of a virtual environment and make him more confident when navigating through the real environment.

Several studies have used virtual environments with blind people using audio (Tzovarus, et al, 2002) and haptic cues (Crossan and Brewster, 2006) to help the player navigate through the game. Studies have also been designed to determine and validate attributes that are necessary to create accessible virtual environments for blind users (Trewin, et al., 2008).

When trying to teach or develop skills in a child, serious videogames have shown a great potential (Gee, 2003) and are also highly motivating, which is a key advantage when trying to teach something to a student (Gee, 2003). These characteristics make videogames a great tool when working with blind children to develop complex skills such as navigation. Several research projects use audio-based videogames to teach school content and learning skills to blind students (Sánchez and Elías, 2007) (Trewin, et al., 2008).

In this paper, we present the results of a usability evaluation study and the impact on the development of orientation and mobility skills as a result of using a haptic-based device (Digital Clock Carpet) and a 3D sound videogame (MOVA3D) in unfamiliar, closed spaces by school-aged, blind children.

II. Software

For this study we have used a videogame called MOVA3D. The game was designed and developed to work with children who are both totally blind and those with low vision (see Figure 1).

Figure 1. *Graphical interface of the MOVA3D videogame*.

In the videogame the player has to navigate through an environment in order to find a certain number of pocket watches on the map. Once he finds and grabs a pocket watch, he has to keep it for 30 seconds while running away from the enemies who try to steal it from him. When navigating, the player's movements are discreet; each step corresponds to a 40 cm movement in the real world, and each turn is at a 30° angle. This was done to

©2010 ICDVRAT; ISBN 978 07049 15022

allow the user to orientate himself in the environment, because as the user is in continuous movement it is difficult for the player to be able to know for certain the degree of his turns or how far he has walked.

A. Interface

The software incorporates attractive 3D graphics that are representative of the real world, as well as stereo sound. The 3D graphics are used to motivate and to provide extra cues for low vision users; however, the software was developed in a way that it is possible to navigate without using the visual cues.

The 3D graphics map the real world into the game. Special care was taken to incorporate the most significant elements of the environment into the videogame to allow the players to create a correct mental representation of the real environment. The colors of the walls and floors in the videogame are also the same as in the real environment.

Stereo sound that emulates 3D sound was used to allow the players to detect each of the elements in the videogame. Different sounds were used to represent different objects (walls, doors, enemies, benches, etc.) and actions (walk, turn left, turn right, open door, go up stairs, etc.). Also, radar was incorporated to help users find the watches when they are located in the same room.

B. Interaction

To play the game users can use the keyboard or a haptic device, which was specially created for this project, called the Digital Clock Carpet (DCC) (see the section below). This device does not allow the player to see the display device at all times while playing, which is why for the first part of the project both input devices were used with the game. However, in the next phase of this research we are only interested in working with totally blind users who are not able to see the screen, so only the DCC will be used.

Players can ask for information relevant to their navigation by pressing the Page Up key (if using the keyboard) or by using a remote USB wireless presentation laser pointer pen. When navigating through the environment, players need to open doors in order to move from one room to another. To do this, players can use the Page Down key (if using the keyboard) or the previously mentioned presentation pointer pen.

III. HARDWARE

The DCC consists of a round wooden structure divided into 12 cells (see Figure 2). The sections correspond to keys that the user can press with his feet. The DCC also has tactile cues that allow the user to recognize where he is standing on the carpet, which is represented by the yellow circles in figure 2.

The idea behind the DCC is to use the clock orientation system for navigation. This means that the space around the user is divided into 30° sections and, for example, if the user needs to turn by 90° he would have to turn to 3 o'clock; if he needs to turn by 210° then he would have to turn to 7 o'clock, and so on.

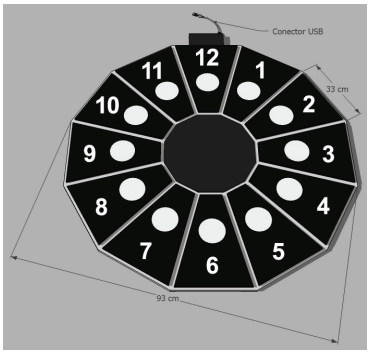


Figure 2. *Diagram of the DCC device.*

IV. EVALUATIONS

An orientation and mobility impact evaluation was performed on a test group of 24 children from 7 to 14 years old, of which 7 were totally blind and the remaining 17 were partially blind with varying ophthalmologic diagnoses.

A. Usability Evaluation

The usability evaluation was performed on 19 end users, all of which were blind children (10 boys and 9 girls) with ages from 6 to 12 years old. Three dimensions were considered: Satisfaction, control and use, and sounds. They were evaluated on a scale of 1 to 10 in which 10 is the highest possible score. The complete results of this research were presented in more detail in a previous paper (Sánchez, Sáenz and Ripoll, 2009).

The end user evaluation of the software shows a high degree of valuation in the 3 dimensions considered, obtaining scores higher than 9 points for all areas. The most highly evaluated scales were satisfaction and sounds, with 9.2 points each. The control and use dimension obtained a score of 9.0 points, while the average evaluation for the three dimensions was 9.1 points.

Proc. 8th Intl Conf. Disability, Virtual Reality & Associated Technologies
Viña del Mar/Valparaiso, Chile, 31 Aug. – 2 Sept. 2010
©2010 ICDVRAT; ISBN 978 07049 15022

B. Orientation and Mobility Preliminary Evaluation

Measurements on the O&M skills of the subjects were taken before and after the intervention to measure both their pre and post game levels, in order to study the impact that the system has on their performance. Three dimensions were evaluated: Orientation and Mobility Techniques, Sensory-Motor Coordination and Sensory-Spatial Orientation.

The activities were carried out during a period of three months in eight sessions that lasted 3 hours and 15 minutes each. In five of these sessions the students worked with the videogame, and in the last session, when the students were thought to have developed a mental image of the environment, they were taken to navigate through the real space that was represented in the software. This last task allowed the evaluators to measure the level of transfer from the videogame that the subjects had achieved.

The results obtained in each of the three dimensions measured are presented in Figures 4 and 5. The first presents the results for children between 7 and 9 years old, while the later presents the results for children from 10 to 14 years old.

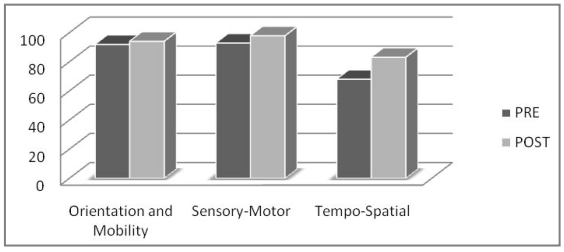


Figure 3. *Pretest/Post-test Comparison in 7 to 9 year old children*.

In the Orientation and Mobility Techniques dimension for 7 to 9 year old users, the pre-test had a mean of 92.0 while the post-test had a higher mean of 94.11 (Figure 3). However, no statistically significant difference was found (Student's t-test = -0.828, p = 0.432, gl = 8). In the 10 to 14 year old group the pre-test had a mean of 78.09 while the post-test had a higher mean of 80.0 (Figure 4). No statistically significant difference was found in this group either (Student's t-test = -0.489, p = 0.636, gl = 10).

For the Sensory-Motor Coordination dimension no statistically significant differences where found either. For the group of subjects from 7 to 9 years old the mean for the pre-test was 92.93, while in the posttest the mean was 97.93 (Figure 3) (Student's t-test = -1.145, p = 0.285, gl = 8). On the other hand, for the group of children with ages between 10 and 14 years old, the mean for the pre-test was 95.55 while the mean results of the post-test was 96.5 (Figure 4) (Student's t-test = -0.726, p = 0.636, gl = 10).

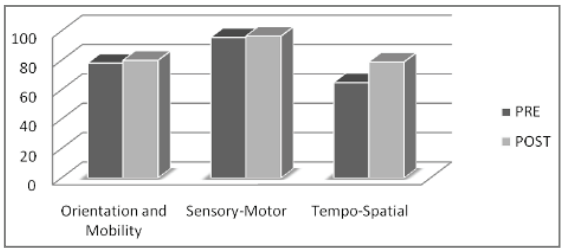


Figure 4. *Pretest/Post-test Comparison in 10 to 14 year old children*.

Finally, for the Tempo-Spatial Orientation dimension, in the group with ages between 7 and 9 years old, the mean of the pre-test was 68.04, which is lower than the mean of the post-test 85.15 (Figure 3). This difference is statistically significant (Student's t-test = -4.973, p = 0.01, gl = 8), which means that there is a higher level of achievement after having used the software. On the other hand, in the group with ages from 10 to 14 years old, the mean of the pre-test was 64.88, which is also lower than the mean of the posttest, 78.91 (Figure 4). This result also presents a statistically significant difference (Student's t-test = -3.648, p = 0.004, gl = 10), which also indicates a higher level of achievement after having used the software.

V. Conclusions

In this paper, we present the results of a usability evaluation and a preliminary cognitive study on the use of a haptic-based device (Digital Clock Carpet) and a 3D sound videogame (MOVA3D) for the development and use of orientation and mobility skills in unfamiliar, closed spaces by school-aged, blind children.

We believe that the learning progress that was made by each child was favored by positive emotional will, interest in the MOVA3D videogame and in the associated DCC device. This allowed them to strengthen their knowledge, which went in favor of acquiring new knowledge regarding the use of the videogame and the associated haptic device.

Without a doubt, the new knowledge allowed the users to integrate new lessons they had learned regarding the environment into the skills involved in the research. Such skills are not only those associated with the ability to adopt postures in line with visual needs in order to be able to perform actions on the carpet (in the case of the participants with low vision), and the ability to situate themselves in space based on an initial position (in the case of the blind users); rather they refer to the

©2010 ICDVRAT; ISBN 978 07049 15022

ability to integrate the clock technique by associating the position of their body with a particular time, processing this information and transforming it into a movement that can be made through the use of the haptic device. This generates movements within the virtual environment and strengthens the conceptualization and construction of a mental map of the space navigated in the videogame, in order for them to be able to then navigate the same route in the real world.

The MOVA3D videogame with DCC and cognitive tasks emerge as an audio-based tool that can be used for the stimulation of tempo-spatial orientation skills in blind children. The children who participated in this study were able to transfer what they learned from the videogame to performing the same tasks in the real world, thus achieving a successful transfer of knowledge and skills. This transfer is not easy because the children feel uncomfortable at first; with time, however, the game becomes a significant tool for training.

VI. Present And Future Work

In this research we seek to evaluate the impact of using videogames based on virtual environments and haptic devices in the development of the orientation and mobility skills of blind users. Some previous results have been promising regarding what can be obtained from such research (Sánchez, Sáenz and Ripoll, 2009). However, an appropriate cognitive study and evaluation has not been done, and is needed to prove these preliminary results. An in-depth study is required, so the research strategy will consist of performing a seven-month case study on each of the participating subjects.

The videogame was modified during the development phase of our research, and since we are interested in working with only totally blind users in the near future, a special effort was made to improve the audio cues for navigation. The visual cues from the original version were maintained so that the facilitators would be able to chart the progress of the users in the game.

The sample will consist of 9 totally blind users with ages ranging from 7 to 15 years old, and which will be divided into three groups based on their age. The first group will be made up of subjects between 7 and 9 years old, the second from 10 to 12 years old, and the third from 13 to 15 years old. The abilities we will measure in each group will differ, based on the existing knowledge and cognitive development in each of the previously mentioned age groups. As such, different evaluation forms will also be used.

One of the key aspects of the evaluation corresponds to the users' sensory skills. Since we are using 3D sound to help subjects navigate through the virtual environment, we are particularly interested in evaluating if their ability to perceive, identify, discriminate and locate sound improves with the use of the software. More importantly, we are also concerned with the subjects' ability to navigate with and without the use of a white cane through the real environments, represented in the virtual environments in which the subjects practice. We expect that they will feel more confident in their navigation and will be able to move through the middle of the rooms instead of around its perimeter.

Acknowledgements

This report was funded by the Chilean National Fund of Science and Technology, Fondecyt #1090352 and Project CIE-05 Program Center Education PBCT-Conicyt.

References

Crossan, A. and Brewster, S. (2006). Two-handed navigation in a haptic virtual environment. In CHI '06 Extended Abstracts on Human Factors in Computing Systems. Montréal, Québec, Canada, April 22 - 27, pp. 676-681.

Gee, J. P. (2003). What video games have to teach us about learning and literacy. Computer Entertainment 1(1), 20-20.

Sánchez, J. and Elías, M. (2007). Science Learning by Blind Children through Audio-Based Interactive Software. Annual Review of CyberTherapy and Telemedicine: Transforming Healthcare through Technology, 5, 184-190.

Sánchez, J. and Elías, M. (2007). Guidelines for Designing Mobility and Orientation Software for Blind Children. In C. Baranauskas et al. (Ed.): INTERACT 2007, LNCS 4662, Part I, 375-388, 2007. © IFIP International Federation for Information Processing.

Sánchez, J., Sáenz, M., and Ripoll, M. (2009). Usability of a multimodal videogame to improve navigation skills for blind children. In Proc. of the 11th international ACM SIGACCESS ASSETS, Pittsburgh, Pennsylvania, USA, October 25 - 28, pp. 35-42.

Trewin, S., Hanson, V. L., Laff, M. R., and Cavender, A. (2008). PowerUp: an accessible virtual world. In Proc. of the 10th international ACM SIGACCESS ASSETS Conference on Computers and Accessibility, Halifax, Nova Scotia, Canada, October 13 - 15, pp. 177-184.

Tzovarus, D., Nikolakis, G., Fergadis, G., Malasiotis, S., and Stavrakis, M. (2002). Design and implementation of virtual environments for training of the visually impaired. In Proc. of the 5th International ACM SIGACCESS ASSETS, pp. 41-48.

©2010 ICDVRAT; ISBN 978 07049 15022

Author Index

	Paper	Abstract
Adamovich, S V	131	*xxxiii*
Ahmed, A	249	*xlvii*
Baptista, A	79	*xxvi*
Barrett, J	17	*xix*
Battersby, S	139	*xxxiv*
Bauminger, N	295	*lii*
Biswas, P	203	*xli*
Broeren, J	115	*xxxi*
Brown, D J	139	*xxxiv*
Brown, S H	147	*xxxv*
Buckwalter, J G	213	*xlii*
Budziszewski, P	27	*xx*
Burke, J W	195	*xl*
Cao, X	71	*xxv*
Cárdenas-López, G	103, 291	*xxix, lii*
Cassinelli, A	157	*xxxvi*
Chance, E	165	*xxxvii*
Chang, C Y	223, 249	*xliii, xlvii*
Charles, D K	195	*xl*
Cheng, S	249	*xlvii*
Cherni, H	85	*xxvii*
Chieng, C L	223	*xliii*
Chihara, K	61	*xxiv*
Cikajlo, I	235	*xlv*
Cobb, S V	93, 295	*xxviii, lii*
Connell, L	139	*xxxiv*
Costa,, R M E M	1	*xvii*
Crosbie, J H	195	*xl*
Crucian, G P	7	*xviii*
Dalrymple-Alford, J C	7	*xviii*
De la Rosa-Gómez, A	103	*xxix*
Dietz, A	123	*xxxii*
Difede, J	213	*xlii*
Douguet, A-S	71	*xxv*
Dünser, A	7	*xviii*
Dzwiarek, M	27	*xx*
Edelmayer, G	17	*xix*
Eden, S	295	*lii*
Floratos, N	17	*xix*
Fluet, G G	131	*xxxiii*
Flynn, S M	185, 223, 249	*xxxix, xliii, xlvii*
Forbell, E	213	*xlii*
Gal, E	295	*lii*
Gamito, L	79	*xxvi*
Gamito, P	79	*xxvi*
Garib-Penna, S	295	*lii*
Geng, Y	249	*xlvii*
Giusti, L	295	*lii*
Glover, T	295	*lii*
Goljar, N	235	*xlv*
Gonzalez, M F	203	*xli*
Grabowski, A	27	*xx*
Hanada, H	263	*xlix*
Hara, T	263	*xlix*
Harvey, A P	17, 273	*xix, l*
Haynes, K	165	*xxxvii*
Helmer, R J N	157, 175	*xxxvi, xxxviii*
Hickey, S	61	*xxiv*
Hogarth, H	17	*xix*
Hurvitz, E A	147	*xxxv*
Hyry, J	61	*xxiv*
Ishikawa, M	157	*xxxvi*
Johansson, B	115	*xxxi*
Jankowski, J	27	*xx*
Joseph, P-A	85	*xxvii*
Kadri, A	85	*xxvii*
Kenny, P	213	*xlii*
Kern, K L	147	*xxxv*
Kim, J	213	*xlii*
Kirner, C	41	*xxii*
Kirner, T G	41	*xxii*
Kitani, M	263	*xlix*
Kizony, R	123	*xxxii*
Klinger, E	71, 85	*xxv, xxvii*
Koenig, S T	7	*xviii*
Kogovšek, D	255	*xlviii*
Kruger, S E	229	*xliv*
Kurkus-Rozowska, B	27	*xx*
Kuroda, T	61, 283	*xxiv, li*
Lacerda, R	79	*xxvi*
Lafond, I	131	*xxxiii*
Lahav, O	33	*xxi*
Langan, J	147	*xxxv*
Langdon, P	203	*xli*

©2010 ICDVRAT; ISBN 978 07049 15022

	Paper	Abstract
Lange, B S	123, 185, 213, 223, 249	*xxxii, xxxix, xlii, xliii, xlvii*
Levene, P	17	*xix*
Levy, S T	33	*xxi*
Liang, W	223	*xliii*
Ljungberg, C	115	*xxxi*
Lundqvist, K	273	*l*
Geng, Y	249	*xlvii*
Giusti, L	295	*lii*
Glover, T	295	*lii*
Goljar, N	235	*xlv*
Gonzalez, M F	203	*xli*
Grabowski, A	27	*xx*
Matjacic, Z	235	*xlv*
Mayer, P	17	*xix*
McConville, K M V	241	*xlvi*
McCrindle, R J	17, 273	*xix, l*
McDonough, S M	195	*xl*
McNeill, M D J	195	*xl*
Mendonça, I	1	*xvii*
Merians, A S	131	*xxxiii*
Miles, M	175	*xxxviii*
Millen, L	93, 295	*xxviii, lii*
Milosevic, M	241	*xlvi*
Morais, D	79	*xxvi*
Morie, J F	165	*xxxvii*
Morrow, P J	195	*xl*
Muñoz, S	291	*lii*
Nanavati, C	223	*xliii*
Needham, P	17	*xix*
Nyman, S R	17	*xix*
Okamoto, K	283	*li*
Oliveira, J	79	*xxvi*
Ozbič, M	255	*xlviii*
Pacheco, J	79	*xxvi*
Panek, P	17	*xix*
Pareto, L	115	*xxxi*
Parslow, P	273	*l*
Parsons, R	213	*xlii*
Parsons, S	295	*lii*
Patel, H	93	*xxviii*
Plaza Torres, M	109	*xxx*
Qiu, Q	131	*xxxiii*
Ratzon, N	123	*xxxii*
Reger, G	213	*xlii*
Richardson, A	139	*xxxiv*
Rizzo, A A	123, 213, 223, 249	*xxxii, xlii, xliii, xlvii*
Rodríguez, J P	299	*lii*
Rosa, P	79	*xxvi*
Rothbaum, B	213	*xlii*
Rydmark, M	115	*xxxi*
Rudolf, M	235	*xlv*
Sagae, K	213	*xlii*
Saleh, S	131	*xxxiii*
Sánchez, J	51, 299	*xxiii, lii*
Santos, N	79	*xxvi*
Saraiva, T	79	*xxvi*
Sawada, H	263	*xlix*
Schiller, N O	255	*xlviii*
Seok, D	249	*xlvii*
Shefer Eini, D	123	*xxxii*
Si, Y	223	*xliii*
Smith, R	17	*xix*
Soares, F	79	*xxvi*
Souza, D S	1	*xvii*
Standen, P J	139	*xxxiv*
Tabata, Y	283	*li*
Tarruella, A	85	*xxvii*
Tadres, A	51	*xxiii*
Tokarski, T	27	*xx*
Umanski, D	255	*xlviii*
Utsav, K	249	*xlvii*
Valente, J A	41	*xxii*
Victor, C R	17	*xix*
Walker, M	139	*xxxiv*
Wataya, R S	41	*xxii*
Weiss, P L	123, 295	*xxxii, lii*
Wilde, D	157, 175	*xxxvi, xxxviii*
Williams, J	213	*xlii*
Williams, V M	17	*xix*
Xu, M	249	*xlvii*
Yafa, B	123	*xxxii*
Yamamoto, G	61	*xxiv*
Yeh, S-C	123	*xxxii*
Yoshitake, D	61	*xxiv*
Zancanaro, M	295	*lii*
Zerroug, A	157	*xxxvi*

©2010 ICDVRAT; ISBN 978 07049 15022